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VOL. 2

# FIRE CONTROL TECHNICIAN 1 & CHIEF

NAVY TRAINING COURSES

NAVPERS 10177

# FIRE CONTROL TECHNICIAN

## 1 & C

## VOL. II

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10177

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# PREFACE

This book is written as an aid in preparing Fire Control Technicians 2 and 1 for promotion to the rates of Fire Control Technician 1 and Chief Fire Control Technician.

Because of the extensive qualifications required for Fire Control Technician 1 and Chief Fire Control Technician (see appendix III), it has been found advisable to divide the study material into three volumes. This book, designated volume II, covers the general aspects of antiaircraft fire control, general maintenance, ordnance alinement, spotting gunfire, naval gunfire support, and observation and analysis of gunnery exercises. The final volume will be concerned primarily with advanced electronics and radar.

Since men in the Fire Control Technician rating are becoming more and more a group of system or equipment experts, it is the present purpose to include more of the basic material which is applicable to all types of gear, rather than to emphasize a single system. When specific gear is described in the text, it is done chiefly for the purpose of applying certain basic fundamentals or to show the applications of complex materials.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Training Publications Section in the Bureau of Naval Personnel and those naval establishments especially cognizant of the technical aspects of fire control. Special credit is given to the Fire Control Technician School, Class B, Washington, D. C., and the Fire Control Branch of the Bureau of Ordnance, for assisting in the technical review of the text.

# READING LIST

## NAVY TRAINING COURSES

*Fire Controlman 3*, Vol. 1, NavPers 10163–A.
*Fire Controlman 3*, Vol. 2, NavPers 10164–A.
*Electricity for FC & FT*, Vol. 1, NavPers 10170.
*Electricity for FC & FT*, Vol. 2, NavPers 10171.
*Fire Controlman 2*, Vol. 1, NavPers 10035–A.
*Fire Controlman 2*, Vol. 2, NavPers 10035–B.
*Fire Controlman 2*, Vol. 3, NavPers 10035–C.
*Fire Control Technician 1 & C*, Vol. 1, NavPers 10176.
*Electricity*, NavPers 10622–B.
*Fire Control Fundamentals*, NavPers 91901.
*Radar Electronic Fundamentals*, NavShips 900016.
*Radar System Fundamentals*, NavShips 900017.
*Electronics Technician 2*, Vol. 1, NavPers 10190–A.
*Advanced Mathematics*, NavPers 10071.
(Chapters 1, 2)
(Chapters 6, 7, 8)
(Chapters 9, 10, 11)

## OTHER PUBLICATIONS

*Naval Ordnance and Gunnery*, Chapters 24, 25, 28, 32, 33, NavPers 16116–B.
*BuOrd Manual* (1943) (With changes 1–10), Chapters 1A, B, F; 2; 3; 11.

## USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for supplementary reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

| **Correspondence** | | **Self-Teaching** | |
|---|---|---|---|
| X 147 | *Trigonometry* | EM 311 | *Plane Trigonometry* |
| CB 785 | *Electrical Measuring Instruments* | MB 785 | *Electrical Measuring Instruments* |

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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# FIRE CONTROL TECHNICIAN 1 & C

## Vol. II

# CHAPTER 1

## THE AA FIRE-CONTROL SYSTEM—BALLISTICS

When you first looked at a rangekeeper, it appeared to be a conglomeration of gears, shafting, and wires. But as you became familiar with basic mechanisms, you found that it was an orderly arrangement of instruments designed to solve the fire-control problem. You learned about these basic mechanisms, and how they solved surface FC problems, from previous study and experience.

You now will learn how aerial FC problems are solved by these same basic mechanisms. If you thoroughly understand the air problems solved by a computer, you will have no trouble in learning to isolate and rapidly analyze troubles in AA systems.

Like surface-fire systems, AA fire-control systems compute ballistic corrections for wind, drift, *I. V.* loss, and relative target motion to lay the gun so as to hit the target at the future target position. The basic analytical descriptions of surface-fire ballistics are also valid for AA fire; however, additional factors must be considered. There are two methods of solving the AA problem for gun orders, and both are extremely important. The first method, which we will take up in this and succeeding chapters, is the vector or linear-rate solution used by the Mk 37 gun fire-control system; the second, which will be discussed later in this book, is the relative rate solution used by other AA systems such as the Mk 56 gun fire-control system.

The factors which influence the trajectory of a projectile can be considered first, thereby simplifying our later discussion of own ship and target motion, and predictions and corrections for the roll and pitch of the ship.

## AA BALLISTICS FOR STATIONARY TARGETS

In figure 1–1, point *T* represents a stationary aerial target. Suppose you set your sights on the target and find they are elevated 20° above the horizontal. This angle, target elevation above the horizontal, also called position angle, is represented by the symbol *E*. In the figure the distance to the target, as measured along the line of sight by the rangefinder or radar, is 13,600 yards. This distance is the slant range *R*.

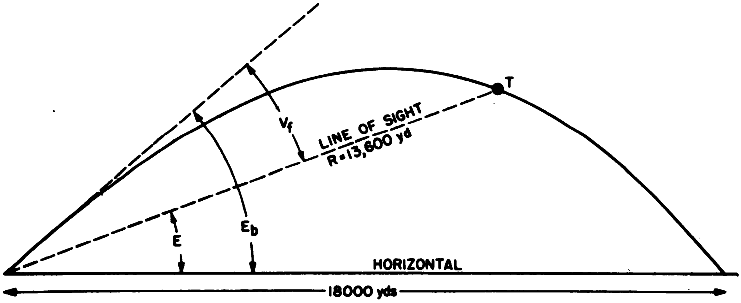

**Figure 1–1.—An AA trajectory.**

Now suppose you find that, if you elevate the gun 40° above the horizontal, the projectile will hit the target, (neglecting drift and other deflection effects for the moment). However, if you look at a 5-inch range table, you will find that a range of 18,000 yards corresponds to the angle of departure of 40°. This means that the trajectory of the shell touches the horizontal plane at a distance of 18,000 yards if the angle of departure is 40°.

Using the same combination of mathematics and experiment by which the 18,000-yard figure was obtained, ballistic experts can calculate the distance from the gun at which the trajectory cuts a plane sloping upward at 20°—in this case 13,600 yards—or a plane sloping upward at any other angle.

Standard range calculations produce a range table showing the angles of departure corresponding to different horizontal ranges. Similar calculations, therefore, can produce a "slant range" table showing the angles of departure corresponding to various slant ranges corresponding to 20° elevation of the LOS. Thus, in figure 1–2, a gun elevation of 24° will give you a slant range of 6,000 yards at 20° target elevation. For 8,000 yards you need 26°30′, and so on. From such a table you could tell the elevation of the gun above the horizontal that would be required to hit any target of known range and 20° elevation. To be useful, of course, such a table would have to be made up for all target elevations.

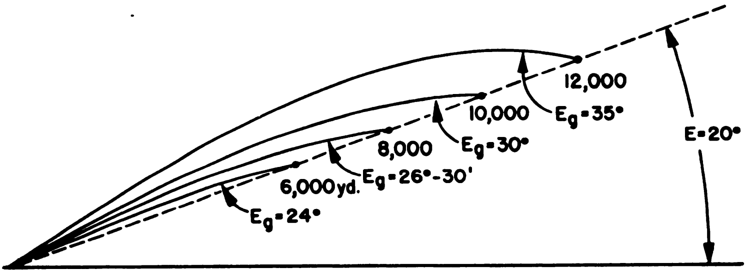

Figure 1–2.—Range and superelevation.

However, as a practical matter, you don't think in terms of elevating the gun above the horizontal. You elevate it above the LOS. In local control, you set the sight angle onto the gun sights and then keep the sights on the target. And, in director control, you form gun elevation order by adding a computed sight angle to director elevation. The angle required is therefore the angle of gun elevation above the line of sight. This angle is called superelevation and is represented by the symbol $Vf$ (fig. 1–3). Briefly, superelevation is the angle the gun must be elevated above the predicted target elevation to allow or compute for the curvature of the trajectory in a vertical plane.

In the case of a motionless target and standard conditions, superelevation is equal to sight angle. When the target is moving, it is necessary to lead the target in elevation. In

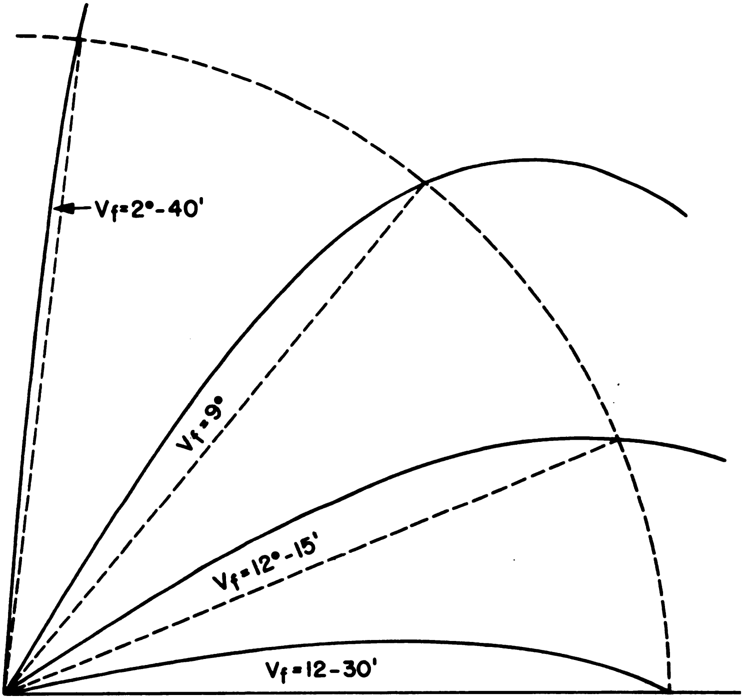

Figure 1–3.—Elevation and superelevation.

this case the lead angle is added to superelevation along with corrections for wind, and sometimes, *I. V.* loss, in order to form sight angle, *Vs*.

## THE THREE-DIMENSIONAL CAM

You have seen that a table similar to a range table could be compiled, giving the superelevation required to reach any desired range along a 20° LOS. Obviously, you could make a ballistic cam from the information contained in such a table.

Such a cam would be similar to the ballistic cams in a surface rangekeeper . You would use a straight line approximation based on a function of range—thus $Vf=KR$. The cam would be rotated by range, and the cam output would be the difference of each range between the straight line approximation and the actual value of *Vf*. Then *KR*2, from a gear reduction, would be combined in a differential with the cam output to give the proper value of *Vf*.

**For** a particular slant range, however, superelevation varies with the angle of target elevation. Superelevation is largest at zero elevation (fig. 1–3), decreases slowly at first

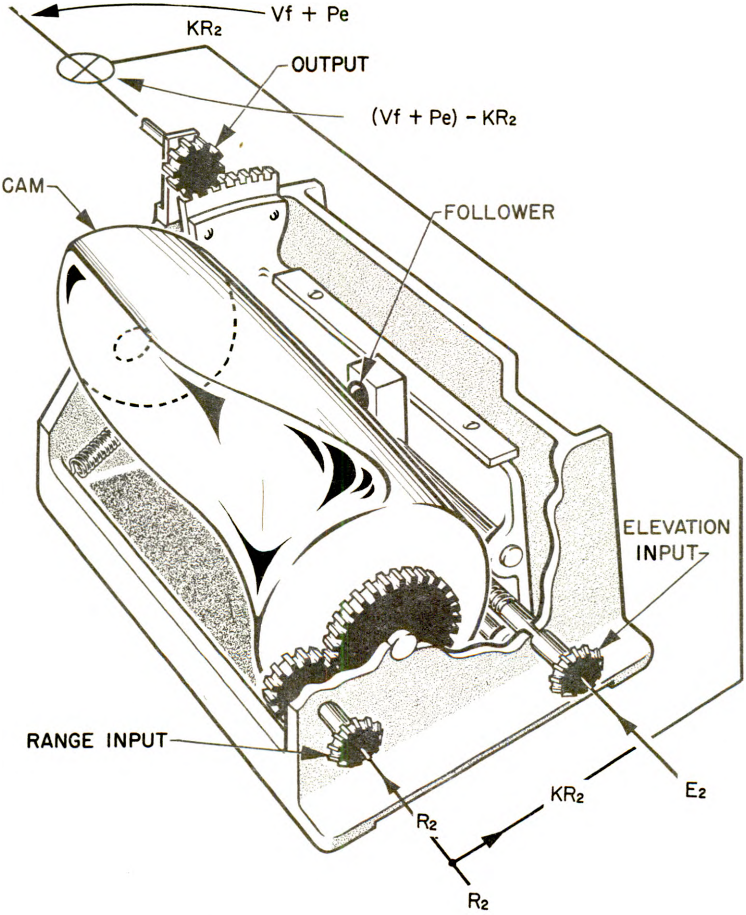

Figure 1–4.—Construction of a three-dimensional (ballistic) cam.

as the elevation increases, then decreases quite rapidly at high elevations. You can see that for a target directly over head superelevation would be zero.

Clearly, then, a ballistic cam which gives you correct values of superelevation for a target elevation of 20° won't work if the target elevation is 19° or 21°. In other words you must have an additional cam for each target elevation to compute the correct value of superelevation.

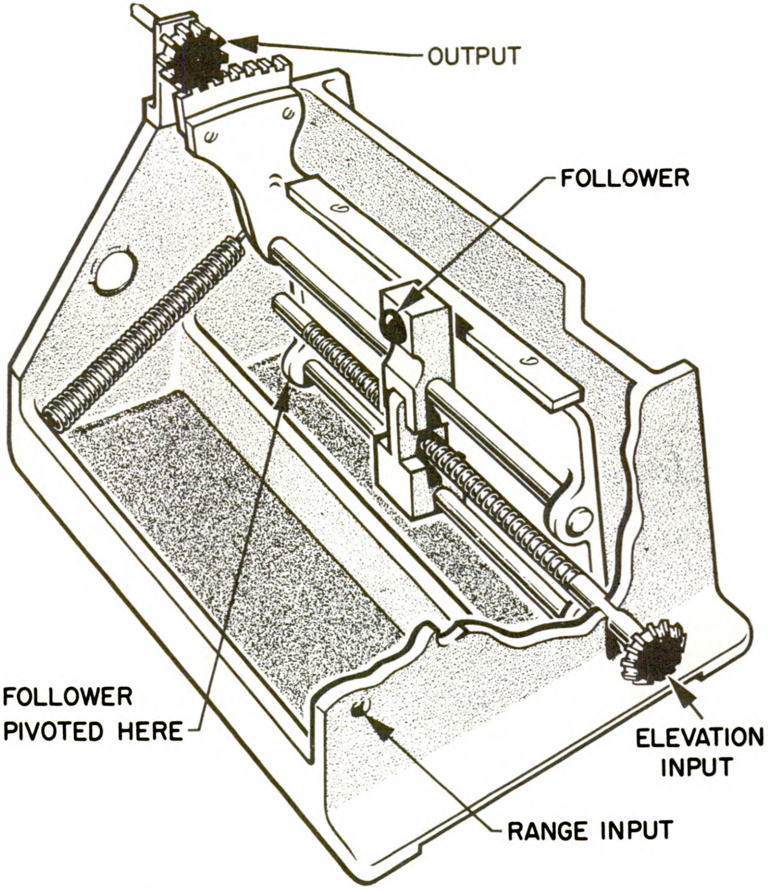

**Figure 1–5.—Additional features of the construction of a three-dimensional (ballistic) cam assembly.**

Now, suppose you use the same straight line approximation in making a series of cams, one for each degree of elevation. Then you could place them in proper order next to the 20° cam on the same shaft. The cam follower could be designed to move back and forth to the particular cam you want. Finally, if you smooth off the "steps" between the cams, you would have a single continuous three-dimensional or ballistic cam such as the one shown in figure 1–4.

The Mk 1A Computer's $Vf$ and $Pe$ Ballistic Computer employs this type of cam. The follower is moved to a position corresponding to the value of a predicted target elevation $E2$. (See fig. 1–5.) It is driven by a small screw which is rotated by the elevation input. The cam itself is then rotated to the proper value of range by the range input $R2$. The cam output will be $(Vf+Pe)-KR2$, as shown in figure 1–4. Combine $KR2$ to this output by means of a differential and you have the value of superelevation required to hit the target.

Summarizing, superelevation is the angle the gun must be elevated above the predicted target elevation to compensate for the curvature of the trajectory. Superelevation increases as range increases, and it decreases as target elevation increases. In the MK 1A Computer superelevation is obtained from the three-dimensional or ballistic cam assembly shown in figures 1–4 and 1–5—the cam is rotated by range input and the cam follower is moved parallel to the cam axis by elevation input.

## THE EFFECT OF DRIFT

In AA fire, just as in surface fire, U. S. Navy projectiles all yaw or drift off to the right. It is necessary, therefore, to deflect the gun to the left to compensate for the effect of drift. It would be possible to obtain values of drift in yards for different ranges and elevations from a three-dimensional cam. In practice, however, drift is derived from sight angle. This is possible because the angular deflection due to drift, $Df$, is roughly proportional to sight angle. In fact:

$$Df=K1Vs+K2.$$

The same relationship, you remember, was used in the rangekeeper for the control of surface fire.

Let us review why drift is related to sight angle. When the projectile leaves the gun, it follows a path or trajectory which is constantly curving downward, away from the line of departure. The projectile is spinning rapidly so that its gyro stability tends to keep it pointing in one direction. But it is following a curved path. The nose of the projectile, therefore, tends to rise above the line of the trajectory as shown in figure 1–6. As soon as its nose rises, air pressure on the underside tries to push its nose farther upward. Because it is a gyroscope, the projectile resists this force and precesses to the right. Soon the projectile's nose is to the right of the trajectory, and air pressure tries to push it farther right (fig. 1–7). This causes downward precession, which continues until the nose is below the trajectory line. Thereafter, precession is to the left and downward, until the nose is left of the line of fire; then upward and to the left until the nose is above the line of fire; then to the right and upward until the projectile nose is right of the line of fire.

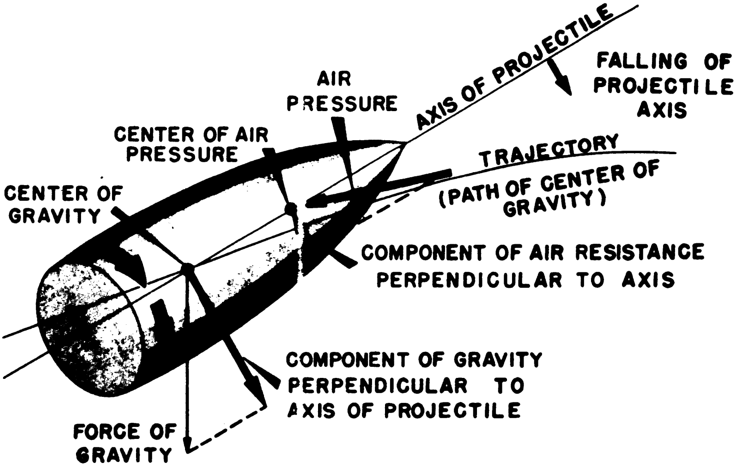
AXIS OF PROJECTILE
FALLING OF PROJECTILE AXIS
AIR PRESSURE
CENTER OF AIR PRESSURE
CENTER OF GRAVITY
TRAJECTORY (PATH OF CENTER OF GRAVITY)
COMPONENT OF AIR RESISTANCE PERPENDICULAR TO AXIS
COMPONENT OF GRAVITY PERPENDICULAR TO AXIS OF PROJECTILE
FORCE OF GRAVITY

Figure 1–6.—The effect of gyroscopic stability.

Thus, whenever the nose is above the trajectory, the projectile precesses to the right, and when it is below the trajectory, it precesses to the left. This causes the average position of the shell to be along the trajectory, i. e., it tends to remain tangent to the trajectory path.

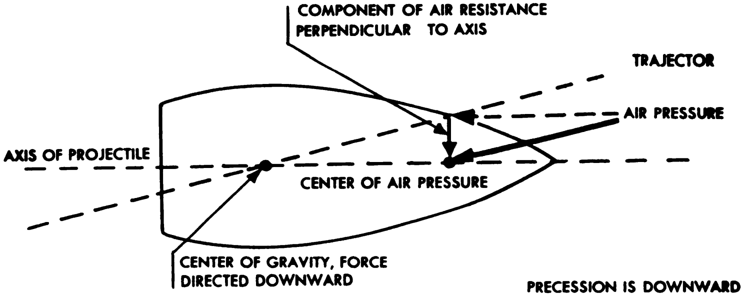

Figure 1–7.—Effect of precession, looking down on the projectile.

Remember, though, that when the shell moves along the trajectory it is constantly falling downward. This causes the nose of the projectile to remain above the line longer than below. The net result is that the air pressure acting on the underside of the projectile nose causes a rightward drift.

You can see that the amount of drift will depend upon the curvature of the trajectory. And the curvature of the trajectory depends upon sight angle. The amount of drift is therefore proportional to a function of sight angle.

Total linear deflection due to drift is approximately equal to the rate of drift times the slant range. And the deflection angle in mils due to drift, $Df$, will be the linear drift divided by the slant range in thousands of yards. Drift deflection angle $Df$ is therefore proportional to $Vs$.

## CHANGES IN INITIAL VELOCITY

The values of superelevation, $Vf$, and drift, $Df$, give you the complete picture of the AA trajectory under theoretical range-table conditions with a motionless target, standard initial velocity, and still air of standard density. However, the laboratory conditions under which these quantities are calculated never exist in practical gunnery. So, just as in surface fire, it is necessary to correct for variations from the standard, with one exception; no correction is ever attempted for nonstandard air density in AA fire.

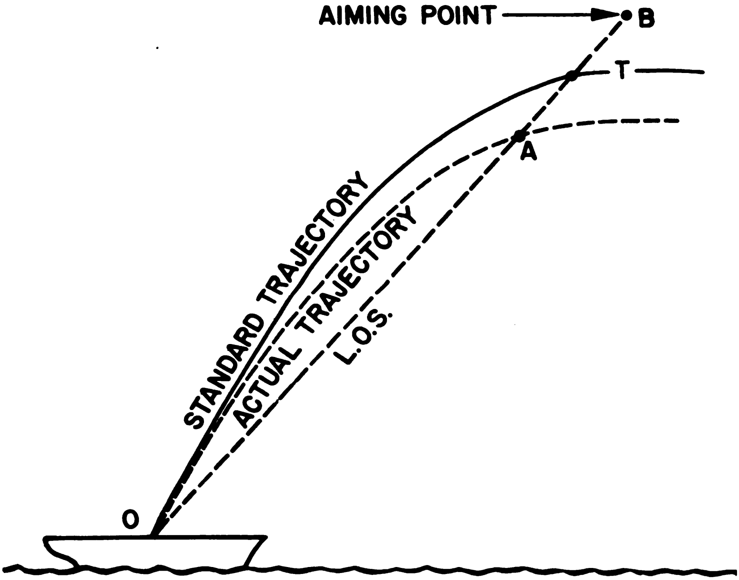

Figure 1–8.—The error due to changes in initial velocity.

If the projectile travels slower due to the loss of *I. V.*, it will take longer to cover any 100-foot length of the trajectory. Gravity will have longer to act, and the projectile will fall farther. Thus the actual trajectory will be more curved and shorter than the standard trajectory, as is shown in figure 1–8. As a result, the projectile will fall short; it will cross the LOS at less than the proper slant range. The error shown in figure 1–8 is the distance *AT*.

This error is allowed for in AA gunnery in about the same way that it is in surface fire. The slant range is increased by an amount equal to the error. A moment's thought will show you that distance *AT* is roughly equal to (*I. V.* loss) $\times Tf$. Therefore, this quantity is added to slant range, and a superelevation corresponding to the revised range is used.

In older AA computers, such as the Mk 10 rangekeeper, this was the only correction made. However, it has been found that you get closer to the target by adding a couple of other approximate corrections. In the Mk 1A computer the range correction (*Rm*) due to changes in *I. V.* is obtained by means of a gear ratio on the *I. V.* shaft line. Thus it will be proportional to the change in *I. V.*

As you can see, the value of superelevation corresponding to the revised slant range is further corrected by a small angle *Vfm*, the correction to superelevation for a change in *I. V.* from the standard 2,550 feet second. *Vfm* is equal to *K* (*I. V.* loss).

## HOW WIND AFFECTS AA FIRE

As with surface fire, corrections for wind in AA fire are only approximate. The correction due to wind is based on the assumption that wind is always horizontal and its force and direction are the same throughout the trajectory of the projectile. Sometimes a ballistic wind is used. More often, however, time doesn't permit a calculation of a ballistic wind so the observed wind is used.

The first step in computing a wind correction is to separate the wind into range and deflection components. The method of resolving wind into its component vector here is a little more exact than the method used in surface fire. In the surface problem you obtained components along and across the LOS. The angle *Ds* between the line of sight and the line of fire was so small that it could be disregarded in wind computations. But in AA fire you usually have to lead a fast target, which makes a large angle between the line of fire and the line of sight. Components of wind are therefore taken along and across the LOF in computing the AA problem.

In order to obtain the wind components relative to the LOF, you figure out the angle between the wind and the

LOF. This angle is called *Bwg*. Figure 1–9 shows you how the various angles involved are measured. *Bw* is true wind direction, a known quantity. *B* is true target bearing, which can be obtained by adding measured relative target bearing to own ship's course, and *Ds* is the deflection angle. Therefore

$$Bwg = B + Ds - Bw.$$

There is an approximation in this use of *Ds* which will be explained later, but it is accurate enough for the purpose. The components of wind speed *Sw* can be computed by taking *Bwg* as one input to a component solver and *Sw* as the other input. The outputs would then be range component of wind *Ywg*, and cross wind component *Xwg*.

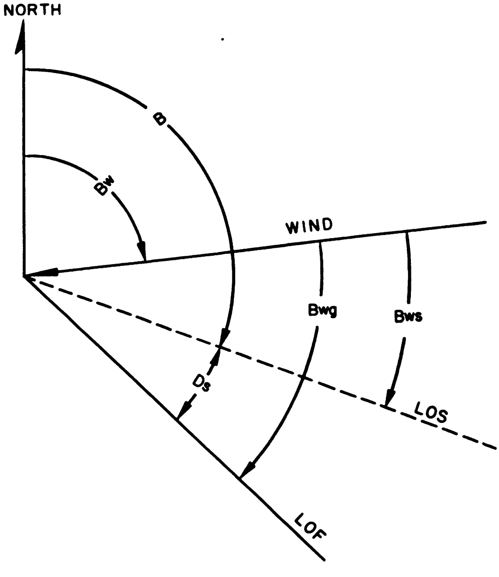

Figure 1–9.—Wind angles about the line of fire.

When it is necessary to use relative wind, you add the components of own ship's motion to the wind components which gives the following relative wind components—

$$Ywgr = Ywg + Yo,$$
$$Xwgr = Xwg + Xo.$$

Actually, of course, $Yo$ and $Xo$ are computed relative to the LOS rather than the LOF, but this is an allowable approximation in the calculation of the relative wind components.

## WIND IN DEFLECTION

The effect of cross wind is the same in AA fire as in the surface problem. The projectile is pushed sideways. The distance of displacement depends upon the force of the cross wind and the time of flight. As you may remember from your study of the surface problem, linear deflection due to wind is equal to $Xwgr\ Tf$ multiplied by a constant $K1$, where $K1$ is a variable quantity which varies with range. This deflection is then converted to angular mil measure by dividing by range.

The formula for computing the deflection correction to compensate for the effect of apparent wind is

$$Dw = \frac{K1\ Wrd\ Tf}{R}.$$

The Mk 1A does not compute $Dw$ separately. $Dw$ is combined with the deflection prediction to compensate for the movement of own ship and target. You will see how this is done after studying the computation of ballistics for a moving air target.

## RANGE COMPONENT OF WIND

It remains to figure out the effect of the range component $Ywgr$. Although this is referred to as a range component, you must realize that it is not directed along the LOF. It is a horizontal component which lies in the vertical plane containing the LOF. It is obvious, from figure 1–10, that the component $Ywgr$ tends to push the projectile back, shortening the range. But it is equally obvious that its full force isn't being exerted to retard the projectile. Only that component of $Ywgr$ acting ALONG the slanting line of fire is working to slow down the projectile.

This slant range component of wind is called $WrR$. From figure 1–10, we see that

$$WrR = Ywgr \cos E.$$

$WrR$ is obtained from a component solver with $Ywgr$ as the speed input and $E$ as the angle input.

Using an approximate formula to compute the range correction for wind, we can write

$$Rw = K1\ WrR\ Tf.$$

This $Rw$, the range prediction to compensate for the effect of apparent wind on the projectile, is not calculated separately either. It is combined with the range prediction.

This leaves one other component of wind to derive. It acts as an upward force on the projectile perpendicular to

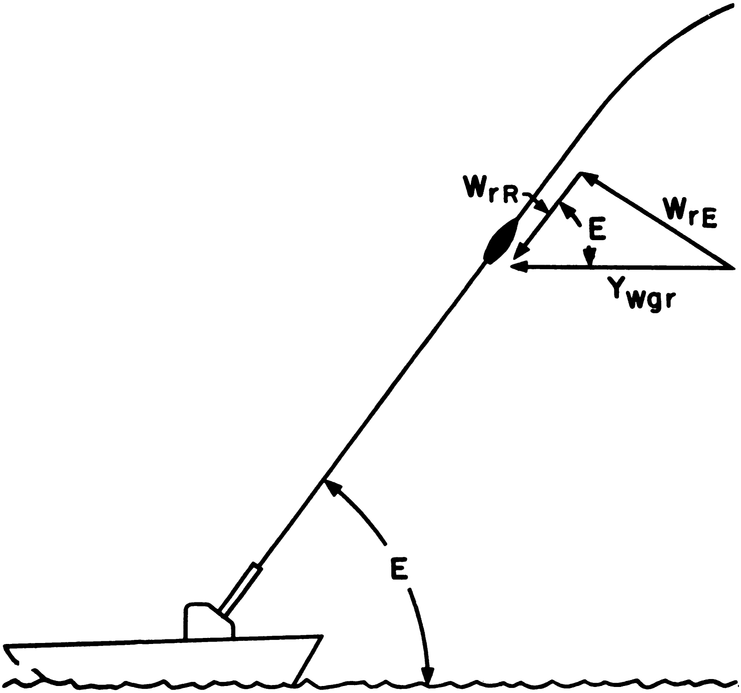

**Figure 1–10.—The horizontal range component of wind.**

the LOF, as shown in figure 1–10. It is computed from the formula

$$WrE = Ywgr \sin E.$$

A study of the figure indicates that this component of wind necessitates a correction to sight angle. The angular correction in mils is given by the approximate formula

$$\frac{Vw = K1 \text{ WrE Tf}}{R}$$

*Vw* is the elevation prediction to compensate for the effect of apparent wind on the projectile. It does not exist separately in the machine and will be considered later when we discuss elevation prediction for own ship and target motion.

## SIGHT ANGLE AND SIGHT DEFLECTION

Thus far we have covered the corrections to the LOF for a stationary elevated target. Bringing the corections together, the gun is elevated above the LOS by an angle equal to the sum of superelevation, elevation effect of wind, part of the *I. V.* loss correction, and the elevation spot:

$$Vs = Vf + Vw + Vm + Vj.$$

It should be noted here that *Vf* is based on the gun range, or advance range, to future target position.

The advance range to a stationary air target, corrected for effect of apparent wind, *I. V.* loss, and range spot, can also be computed at this point:

$$R2 = R + Rw + Rm + Rj.$$

From these formulas we see that the effects of wind and *I. V.* loss enter into sight angle twice, (1) as a correction to range which affects the value of superelevation, and (2) as a direct correction to sight angle.

In addition, the gun must be deflected to one side of the LOS. The deflection angle is given by

$$Ds = Dw + Df + Dj.$$

*Ds* is measured in the slant plane and is the quantity you set on the gun sight for local control. (See fig. 1–11.) The

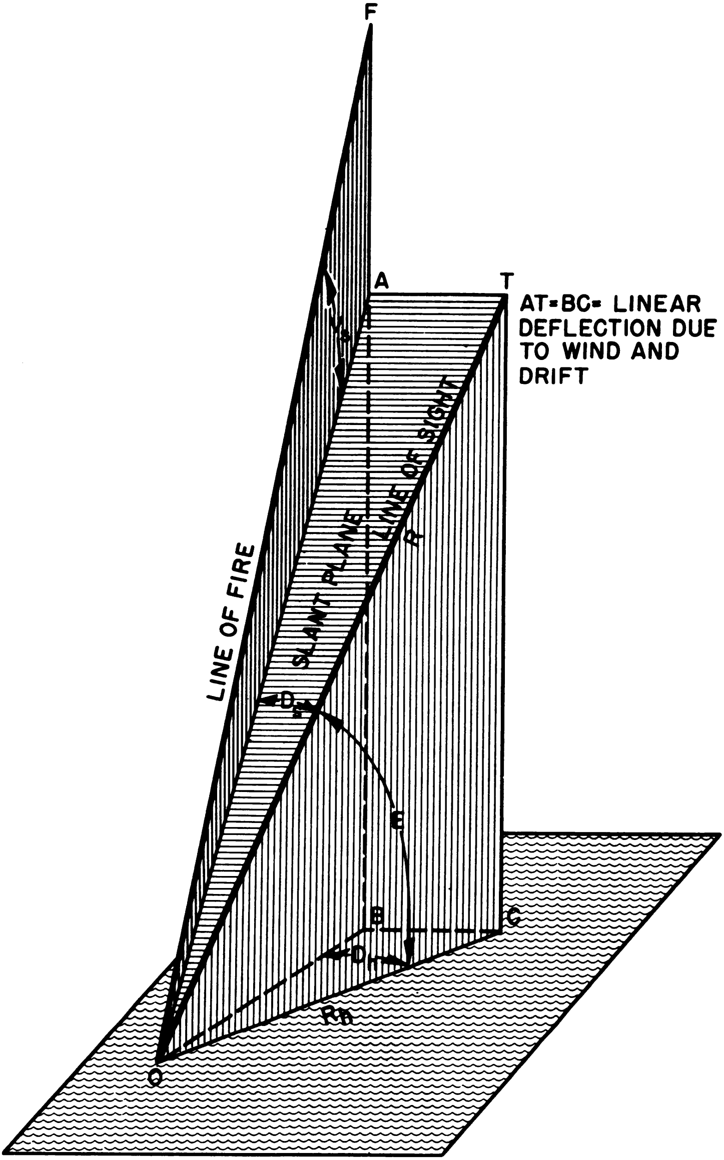

Figure 1–11.—*Ds* and *Dh*.

reason for figuring *Ds* this way lies in the construction of the once popular yoke-type gun sight. The yoke rotates in deflection about a pivot pin which is perpendicular to the LOS. In other words, the telescope is deflected (traverses) in the slant plane, and *Ds* is the angle the sight setter sets in on the deflection bar of the gun sight.

In figure 1–11, *Ds* is smaller than *Dh*, even though *BC* is equal to *AT*. This is because *R* is larger than *Rh* due to target elevation. Thus, the gun sights are deflected through angle *AOT* in the slant plane, whereas the mount is trained through the larger angle *BOC* in the deck plane (assuming the deck to be horizontal). The relationship of these slant-plane and horizontal-plane angles is quite simply defined in the formula.

$$Dh = Ds \sec E.$$

The computer, however, does not use this formula although the principle used is the same. *Ds* is transferred to the deck plane in the partial-deck-deflection computer while being treated for trunnion tilt—this will be discussed in more detail later. Meanwhile, *Ds* is transmitted to the gun by synchro for local control.

## QUIZ

1. Superelevation is greatest at what target elevation?
   a. Zero.
   b. 45°.
   c. 65°.
   d. 90°.
2. In the Mk 1A computer, superelevation is computed
   a. from an approximation of *Vf*.
   b. with a three-dimensional cam.
   c. from a function of target elevation.
   d. with a flat ballistic cam positioned by range and elevation.

3. Drift correction is computed as a function of
   a. advance range.
   b. initial velocity.
   c. sight angle.
   d. advance target elevation.
4. When the nose of the projectile is below the trajectory, precession causes drift
   a. to the right.
   b. to the left.
   c. upward.
   d. downward.
5. When *I. V.* decreases, the drift correction is
   a. increased.
   b. decreased.
   c. not affected.
   d. inaccurate.
6. The range input to the three-dimensional cam assembly
   a. rotates the follower screw.
   b. drives the differential without modification.
   c. enters only into the computation of the straight line function.
   d. rotates the cam.
7. Superelevation decreases as
   a. range increases.
   b. sight angle decreases.
   c. drift increases.
   d. target elevation decreases.
8. Drift increases as
   a. elevation decreases.
   b. range decreases.
   c. sight angle decreases.
   d. superelevation decreases.
9. The angle between true wind and the LOF is $Bwg$ which is computed from
   a. $B - Ds + Bw$.
   b. $Ds + B - Bw$.
   c. $Bw + Ds - B$.
   d. $Bw - Ds + B$.
10. When $Sw$ and $Bwg$ are the inputs to a component solver, which one of the following outputs is geared to the sine slide?
   a. $Ywgr$.
   b. $Ywg$.
   c. $Xwgr$.
   d. $Xwg$.

# CHAPTER 2

## THE AA FIRE-CONTROL SYSTEM—OWN SHIP AND TARGET MOTION

Now that you are familiar with the problem involved in hitting a stationary elevated target, you are ready for the more complex part of the AA fire-control problem—hitting a target moving at high speed. The Mk 37 GFCS solves the AA problem to produce the three continuous quantities—gun train, gun elevation, and fuze orders—necessary to burst the projectile as close to the target as possible. Reduced to simplest form, these three answers are diagrammed in figures 2–1, 2–2, and 2–3.

It should be noted that the deck plane is considered to coincide with the horizontal reference plane in these three figures. Locate the following quantities in these first three illustrations and thoroughly study the descriptions for each:

$E$=TARGET ELEVATION: target elevation above the horizontal reference plane. (Fig. 2–1.)

$E'g$=GUN ELEVATION ORDER: the elevation of the gun above the deck, measured in a plane through the gun perpendicular to the deck. (Fig. 2–1.)

$Vs$=SIGHT ANGLE: difference between elevation of gun axis above the horizontal plane and elevation of line of sight above the horizontal plane, measured in vertical plane through gun axis. (Fig. 2–1.)

$B'gr$=GUN TRAIN ORDER: the angle between the fore and aft axis of own ship and the plane through the gun perpendicular to the deck, measured in the deck plane clockwise from the bow. (Fig. 2–2.)

$B'r$=DIRECTOR TRAIN: the angle between the fore and aft axis of own ship and the vertical plane through the LOS,

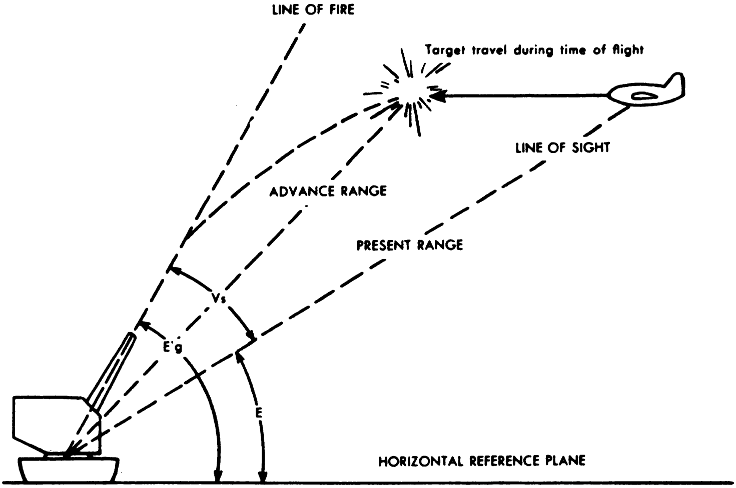
LINE OF FIRE
Target travel during time of flight
LINE OF SIGHT
ADVANCE RANGE
PRESENT RANGE
Vs
E'g
E
HORIZONTAL REFERENCE PLANE

Figure 2–1.—The basic elements of the AAFC problem contained in gun elevation order.

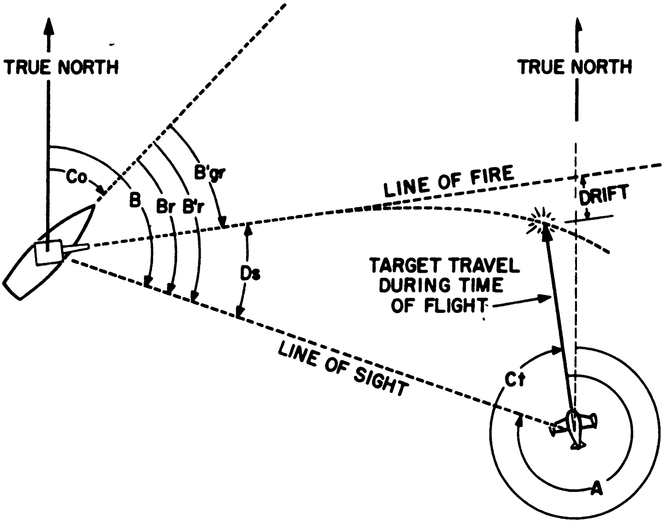

Figure 2–2.—The basic elements of the AAFC problem contained in the gun train order.

measured in the deck plane clockwise from the bow. (Fig. 2–2.)

$Br$=RELATIVE TARGET BEARING: the angle between the vertical plane through the fore and aft axis of own ship and the vertical plane through the line of sight, measured in the horizontal plane clockwise from the bow. As shown in figure 2–2, $Br$ and $B'r$ are equal since the deck plane is assumed to lie in the horizontal reference plane.

$B$=TRUE TARGET BEARING: the angle between the north-south vertical plane and the vertical plane through the LOS, measured in the horizontal plane clockwise from north. (Fig. 2–2.)

$$(B=Br+Co.)$$

$A$=TARGET ANGLE: angle between vertical plane through direction of motion of target with respect to earth and vertical plane through line of sight, measured in the horizontal plane clockwise from direction of motion. (Fig. 2–2.)

$$(A=180°+B-Ct.)$$

$R$=PRESENT RANGE: measured along the LOS. (Fig. 2–3.)

$R2$=ADVANCE RANGE: predicted range to future target position. (Fig. 2–1.)

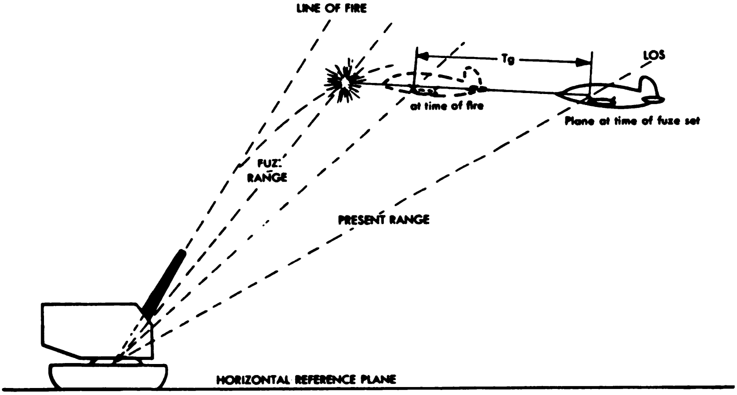

**Figure 2–3.—The basic elements of the AAFC problem contained in the fuze order.**

*R*3=**FUZE RANGE**: the range at which the target will be when the projectile now being fired bursts. Fuze range is advance range plus a correction for the time required to load the projectile. (Fig. 2–3.)

*Tg*=**DEAD TIME**: the time in seconds between cutting the fuze and firing the projectile. Dead time is illustrated in figure 2–3 by the distance the target has traveled between cutting the fuze and firing the projectile.

*Ds*=**SIGHT DEFLECTION**: the angle between the vertical plane through the LOS and the vertical plane through the axis of the gun, measured in a plane perpendicular to the vertical plane through the LOS. *Ds* is positive if the gun is trained clockwise from the LOS. (Fig. 2–2.)

*Ct*=**TARGET COURSE**: the angle between the north-south vertical plane and the vertical plane through the direction of motion of the target with respect to earth, measured in

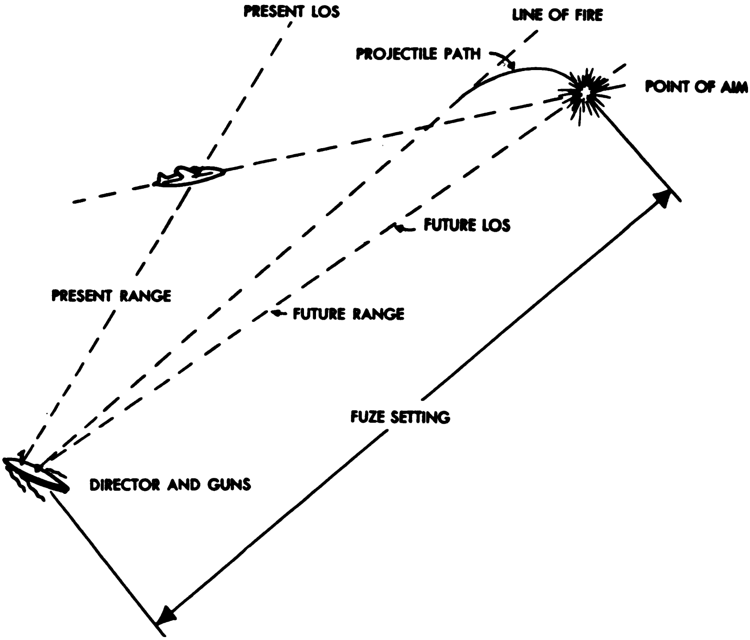

Figure 2–4.—The main components of the AA problem.

the horizontal plane clockwise from true north. (Fig. 2–2.)

*Co*=OWN SHIP'S COURSE: the angle between the north-south vertical plane and the vertical plane through the fore and aft axis of own ship, measured in the horizontal plane clockwise from true north. (Fig. 2–2.)

If we make a few preliminary assumptions, the problem will be much easier to solve—the complicating factors can be added later. If we assume a stable reference plane, zero wind velocity, and the elimination of parallax by locating the director and gun at the same theoretical point on the ship, the basic problem becomes that of figure 2–4.

Notice that the problem can now be reduced to (1) the determination of the line of fire and (2) the calculation of the fuze setting required to burst the projectile at the future position of the target. (Where proximity fuzes are used the problem reduces to that of determining the line of fire.) We can solve for each part separately. The quantities making up the LOF will be considered first.

## PRESENT TARGET POSITION

As in the surface problem, the present position of the target is our reference point. Two of the coordinates, target elevation and target bearing, are established by the director. The third coordinate, present range, is measured by the rangefinder or radar. Where the director is radar controlled, all three coordinates are established indirectly by means of automatic tracking.

Our first task, then, is to resolve all motion into movement of the target in three coordinates based on the present position of the target. This can be done by considering the motion of both own ship and target as motion of the target relative to own ship.

## RELATIVE MOTION

It must be emphasized that relative target motion is affected by changes in own ship's course *Co*. This is logical because own ship's motion necessitates a greater or lesser rate of director train during the time your ship is changing course. If not compensated for, this would cause an error in the measurement of relative motion. Therefore, relative motion is measured in true bearing coordinates and then modified by the own ship's course input, $Co$, to give relative target bearing $Br$.

## RELATIVE MOTION—SURFACE TARGET

If we assume target elevation to be zero, as with a surface target, the vector resolution of own ship and target motion becomes that shown in figure 2–5a. This, you will recall, is the same method employed in the surface problem where:

$Xo$ (Deflection component of own ship velocity) $= So \sin Br$.
$Yo$ (Range component of own ship velocity) $= So \cos Br$.
$Xt$ (Deflection component of target velocity) $= Sh \sin A$.
$Yt$ (Range component of target velocity) $= Sh \cos A$.

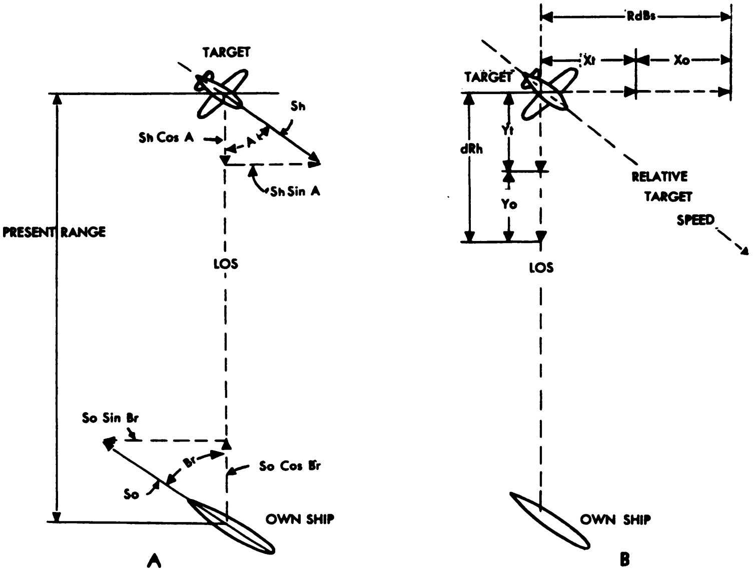

Figure 2–5.—Motion can be considered to be relative motion.

If we combine the *Y* components, as shown in figure 2–5b, the result will be the horizontal range rate component of relative target motion called *dRh*. Likewise, when the *X* components are added we obtain a component across the LOS called linear deflection rate, *RdBs*.

Both *dRh* and *RdBs* are relative motion quantities. We can say, therefore, that the target in figure 2–5b is moving at an apparent rate which is the sum of both own ship and target motion.

## AN ELEVATED TARGET

Unlike the surface problem, an elevated target has three dimensions of motion; therefore, three quantities are needed to define target movement. This is shown in figure 2–6.

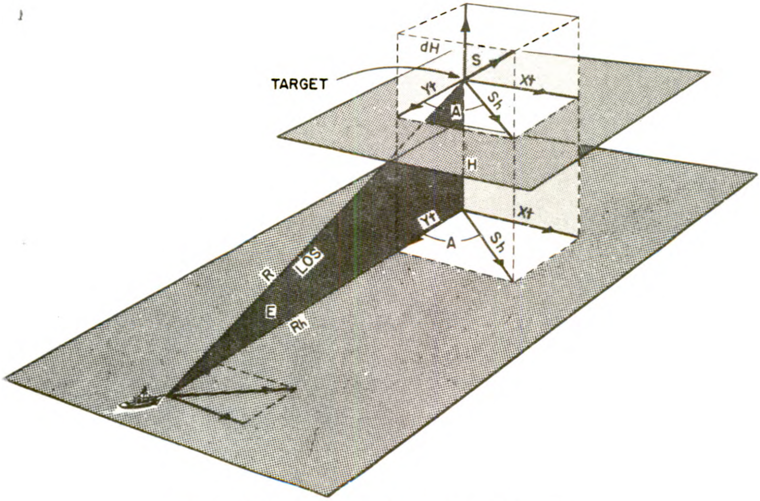

**Figure 2–6.—Motion of an elevated target.**

These quantities are target angle *A*, target horizontal speed *Sh*, and target rate of climb *dH*. *Sh* is defined as the horizontal ground speed of the air target as projected on the horizontal plane. *dH* is defined as the vertical speed of the target. It is equivalent to the rate of change of target height, *H*. It also represents the total vertical relative motion, since own ship moves only in the horizontal.

Notice that $Sh$ and $dH$ are components of the actual air speed of the target, $S$. They indirectly define the inclination of target motion to the horizontal.

In view of what has gone before, you may wonder why $Sh$, $dH$ and $A$ were chosen to define target motion. These particular components were selected for two reasons: (1) it is the easiest set of quantities for the spotter to estimate, and (2) it makes it easy to combine target and own ship speed. The total horizontal component of $S$ can be resolved into two components, $Yt$ and $Xt$. Then $X$ and $Y$ components of own ship and target movement are added in the conventional manner.

The two $Y$ components show you how fast the horizontal range rate $dRh$, measured from own ship to the point directly under the target, is changing. Their sum is the total rate of change of horizontal range. That is:

$$dRh = Yo + Yt.$$

The only components that have any tendency to change the bearing of the target are the $X$ components, since changes

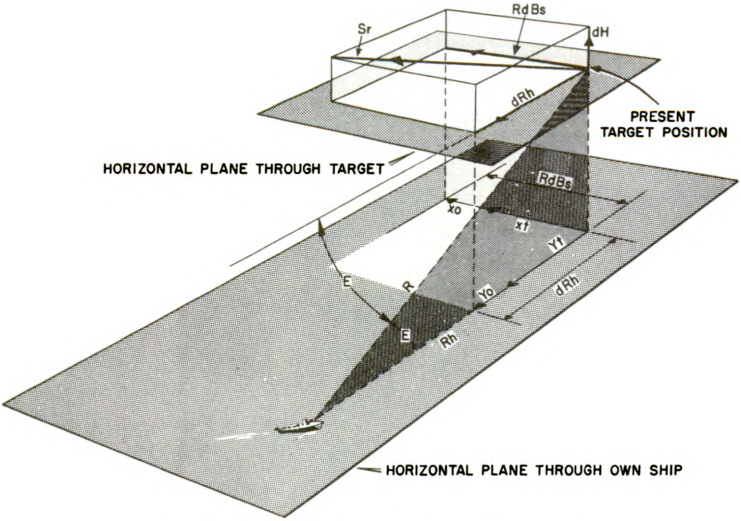
RdBs
Sr
dH
dRh
PRESENT TARGET POSITION
HORIZONTAL PLANE THROUGH TARGET
RdBs
xo
xt
Yt
E
R
Yo
dRh
E
Rh
HORIZONTAL PLANE THROUGH OWN SHIP

**Figure 2–7.—Relative motion of an aerial target.**

in horizontal range or height have no effect on bearing. Therefore, the linear bearing rate is given by the formula

$$RdBs = Xo + Xt.$$

The three vectors $dH$, $dRh$, and $RdBs$ form true rectangular coordinates of a single vector representing the relative speed between own ship and target. This is shown in figure 2–7.

Notice, from figure 2–6, that the vertical height of the target above the horizontal through own ship is obtained by multiplying the slant range $R$ by the sine of $E$. Thus:

$$H \text{ (feet)} = R \text{ (yards)} \times 3 \times \sin E.$$

The horizontal range to a point directly beneath the target is the cos $E$ component of $R$. Thus, we can write:

$$Rh = R \cos E.$$

## LINEAR RATES

The linear rates $dRh$, $dH$, and $RdBs$ are the result of our original selection of the components of target movement which were easiest for the control officer to estimate. These linear rates, however, do not entirely correspond with the three degrees of movement of the Mk 37 director. The director has three degrees of freedom—range, bearing, and elevation. Thus, the director can measure only changes in range along the LOS, changes in target elevation perpendicular to the LOS in the vertical plane containing the LOS, and changes in target bearing at right angles to the LOS in the horizonal plane.

Fortunately, $RdBs$ can be used without modification since it can be projected onto the horizontal plane, as shown in figure 2–7, and is computed at right angles to the LOS. We must, however, calculate the linear rate of change of slant range, and the linear rate of change of elevation perpendicular to the LOS. Both of these quantities are measured in the vertical plane containing the LOS. Figure 2–8 illustrates the two components of relative speed which affect slant range rate; they are $dRh$ and $dH$. (Notice that $RdBs$ has no component along the LOS and therefore has no effect on slant range rate.) It is clear, in this case, that $dRh$ is tending to shorten the range, while $dH$ is tending to lengthen it. You can see from figure 2–8 that slant range rate

$$dR = dRh \cos E + dH \sin E.$$

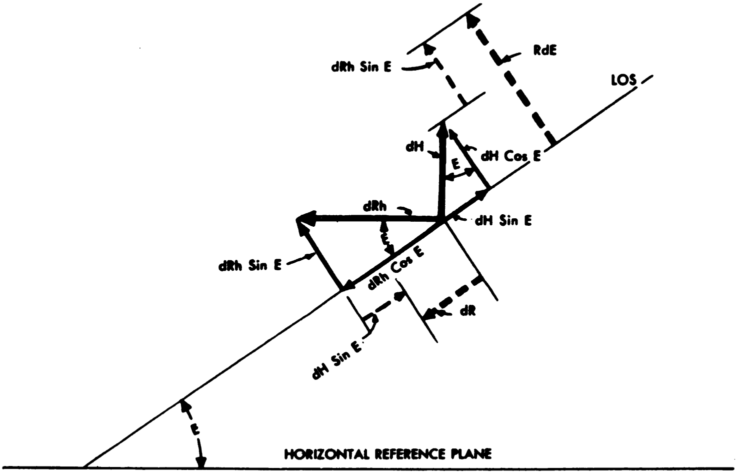

**Figure 2–8.—Direct range rate and linear elevation rate.**

In figure 2–8, $dRh$ is negative, so $dR$ is equal to the difference of the two components. The quantities required can be obtained from a pair of component solvers.

Notice, also, that the components of $dRh$ and $dH$ perpendicular to the LOS are tending to increase target elevation. This means that if the target plane climbs, the elevation angle increases. $E$ also increases if the target plane comes nearer, keeping the same height. Since $RdBs$, the other component of $S$, has no component in the vertical plane, the linear elevation rate is given by

$$RdE = dRh \sin E + dH \cos E.$$

The calculation of $RdE$ and $dR$ completes the resolution of the mutually perpendicular components of motion around the LOS. See figure 2–9. $RdBs$ can be projected onto the horizontal reference plane containing own ship without alteration.

These components—*dR*, *RdBs*, and *RdE*—form the basis for the generated rates and predictions, and they are the final output of the linear-rate section of the Mk 1A com-

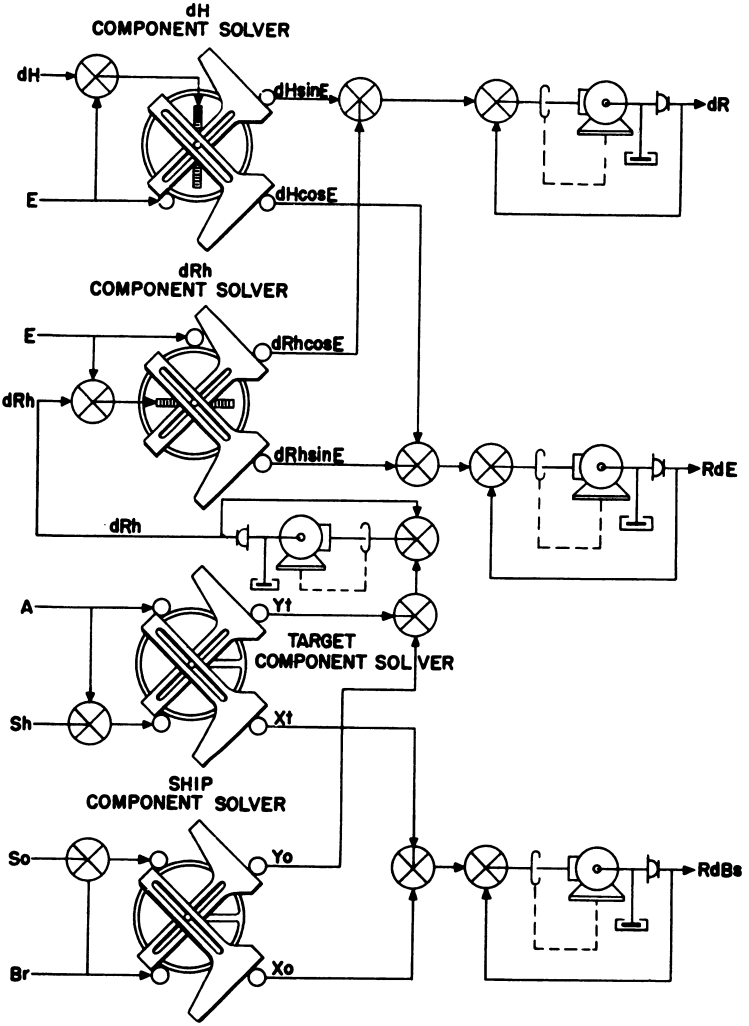

Figure 2–9.—Computation of linear rates.

puter. They are the final output of the own-ship and target component-solver group, and each appears as a servo shaft position.

Figure 2–9 is a schematic diagram showing how the linear rates are computed with four component solvers and a group of differentials. Trace out the entire diagram, and refer to the mathematical expressions shown in figures 2–5, 2–6, 2–7, and 2–8. All the inputs appear on the left, whereas the three outputs appear at the right of figure 2–9. Notice particularly that *RdBs* is made up just as it was in the surface problem; it is the direct addition of the own-ship and target *X*-components. The *RdBs* servo motor merely increases the power sufficiently to drive other computer components. The same applies for the *dR* and *RdE* servos. Also notice that *dRh* from the own-ship and target component solvers is the speed input to the *dRh* component solver, after being amplified by a servo. As previously mentioned, *dH* and *dRh* affect both slant range rate and linear elevation rate. The origin of rate of climb *dH* will be more evident when you study the rate correction mechanisms to be covered later in this book.

## GENERATING MECHANISMS

Three steps are required if accurate values of gun train, gun elevation, and fuze setting are to be continuously and accurately computed: (1) checking and correcting the control officer's estimates of target movement, (2) maintaining a reliable figure at all times for the present value of target range, bearing and elevation, and (3) computing repeatedly the range, bearing, and elevation of the future position of the target—the place it will be when the shell reaches it. The first two steps are performed by the generating mechanism of a computer, the third by the prediction mechanism.

Starting with some known position of the target, the generating mechanism uses the estimated speed and direction of target movement to calculate continuous GENERATED values of present range, bearing and elevation. These generated values are correct only if the estimate of target movement is correct. Therefore, comparison of the generated values with observed values provides a check on the correctness of the estimates.

The size of any errors observed tells you what changes to make in your original estimates.

Thus, by a process of trial and error, accurate values of target movement can be determined. When this is accomplished, a solution is obtained and generated values can be used in place of the observed values if the target is momentarily obscured. More important, you now have accurate information on which to base your PREDICTION of future target position.

The basic method by which AA computers compute generated values is the same as that used in surface fire machines. The RATE at which each of the three quantities—range, bearing, and elevation—is changing at every instant is computed and set up on an integrator.

The integrator is essentially a variable speed transmission. Its output shaft rotates at a speed proportional to the rate at which range, for example, is changing. Therefore, if the output shaft drives a dial or counter which was originally set at the correct value of range, the dial will continue to read a correct value, provided the target continues on the same course at the same speed.

## GENERATED RANGE

We have already computed *dR*, direct range rate along the line of sight. Computing generated range reduces to the problem of computing increments of generated range from the familiar formula

$$\Delta\, cR = dR \times \frac{2027}{3600} \times T.$$

Now, if $\Delta\, cR$ is added to a measured value of present range, the result will be *cR*, generated present range in the slant plane containing the line of sight. This computation is performed by an integrator. The carriage is positioned by *dR*, and a time motor turns the disk at a constant speed. The output, $\Delta$ *cR*, is added to *R* in a differential to furnish generated present range, *cR*, (fig. 2–11).

## GENERATED RELATIVE TARGET BEARING

We know that *RdBs* is a linear motion tangent to circles of radius *R* and radius *Rh*. If we divide *RdBs*, in yards per second, by *R*, the answer will be angular bearing rate, *dBs*, in the SLANT PLANE in mils per second.

Since we have assumed that the deck plane lies in the horizontal reference plane, we can call the slant plane the TRAVERSE plane. The traverse plane is defined as the slant plane containing the line of sight and the sight trunnions. If the ship rolls, the sight trunnions roll; therefore, the traverse plane also rolls. Only when roll and pitch are zero does the traverse plane correspond with the slant plane containing the LOS and *RdBs*.

But, since the director telescopes and the guns are not built so they can traverse, they train in azimuth. The angular bearing rate, therefore, must be calculated in the HORIZONTAL PLANE.

This means *RdBs* must be divided by *Rh* instead of *R* to get *dBs* in the horizontal plane. We know that $Rh = R \cos E$; therefore

$$\text{Angular bearing rate} = RdBs \times .563 \times \frac{1}{R \cos E}.$$

Since we need continuous values of range, *cR* is substituted for *R*. Now if this angular bearing rate is multiplied by time, we will have increments of generated true target bearing in mils.

$$\Delta\, cB = RdBs \times .563 \times \frac{1}{cR} \times \frac{1}{\cos E} \times T.$$

$\Delta$ *cB*, increments of generated true target bearing, can be computed by means of two cams and three integrators (fig. 2–10). The output of an inverse range cam controls the carriage of an inverse range integrator. The disk of the integrator is driven at constant speed by the time motor, so the output roller turns at a speed proportional to *T*/*cR*.

*T*/*cR* drives the disk of a second integrator whose carriage is positioned by the output of a cam which is proportional to $1/\cos E$. In trigonometry, $1/\cos E$ is equal to the secant $E$. This cam, therefore, is called the sec $E$ cam. Likewise, the second integrator is called the sec $E$ integrator.

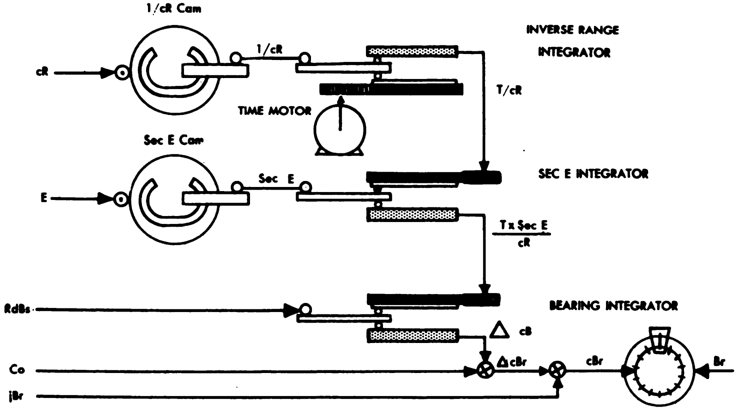

Figure 2–10.—Generated relative target bearing.

The output roller of the sec $E$ integrator drives the disk of the bearing integrator at a speed proportional to $T/cR \times \sec E$. The carriage of the bearing integrator is set by $RdBs$. Hence the speed of the output is $dBs$ sec $E$, and the change in generated bearing $\Delta cB$ is the total turns of the output roller. Thus:

$$\Delta cB = RdBs \times .563 \times \sec E \times \frac{T}{cR}.$$

Own ship course, $Co$, is combined with $\Delta cB$ in order to get change in relative bearing, $\Delta cBr$. Now if this quantity is added to the initial measured value of relative bearing, $jBr$, the answer is generated relative bearing. Thus:

$$cBr = \Delta cB + Co + jBr.$$

## GENERATED ELEVATION

Angular elevation rate is the linear rate, $RdE$, divided by SLANT RANGE. So, generated elevation is obtained by using $RdE$ to set the carriage of the elevation integrator (see fig.

2–11) whose disk is driven by the output of the inverse range integrator, $\frac{T}{cR}$ Therefore, increments of generated elevation are computed from the formula

$$\Delta cE = RdE \times .563 \times \frac{T}{cR}$$

$\Delta cE$ is added to the initial value of elevation in a differential to give $cE$, generated target elevation.

Figure 2–11 is a schematic of the generating mechanism for the Mk 1A computer used with the Mk 37 GFCS. By now you are familiar with schematics and shouldn't have any difficulty tracing the outputs of *cE*, *cR*, and *cBr* from the inputs of own ship and target course and speed.

## PREDICTING TARGET POSITION

The remaining problem in dealing with target motion is to predict the range, bearing, and elevation of the point which the target will occupy when the projectile arrives. Referring again to figure 2–4, we see that this is the point of aim. The LOF, however, is elevated above this point by the value of superelevation.

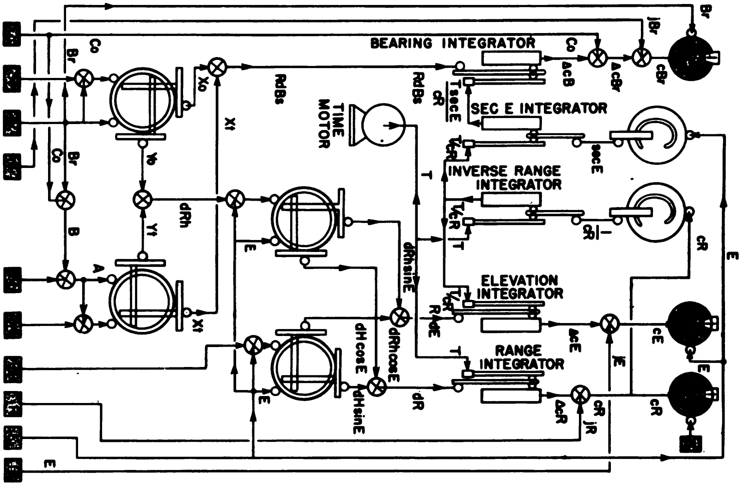

Figure 2–11.—An AA generating mechanism.

Now that we have established the direction and speed of target motion by the three linear rates *dR*, *RdBs*, and *RdE* (fig. 2–9), the predictions aren't difficult. You may not have visualized these rates as components of relative target movement, but remember, *dR* was obtained by adding the components along the LOS of the three original components *dRh*, *RdBs*, and *dH*. Since *dR* includes the components along the LOS of all three components of relative target movement, it includes all the motion of *S* along the LOS and must itself be a component of the relative movement. Similarly, *RdE* and *RdBs* are components of the relative movement.

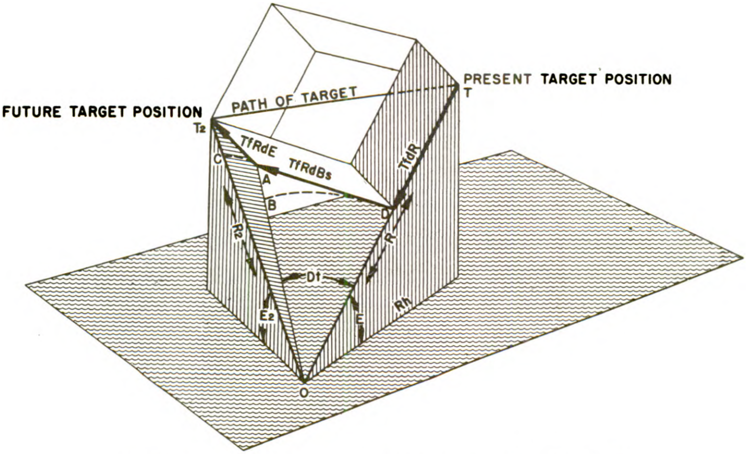

Figure 2–12.—Components of relative motion during *Tf*.

Bear in mind that, considered as rates, *dR*, *RdBs*, and *RdE* are momentary constantly changing values. Considered as components of relative target motion, however, they have fixed values as long as target motion remains unchanged.

Suppose that, at a given instant, you calculate a quantity *dR* which is both the range rate and a component of target movement along the LOS. Ten seconds later this quantity is still a component of relative target movement. However, because the direction of the LOS has changed during this interval, the component is no longer directed along the new

LOS. Therefore, it no longer represents range rate. As a result, to find the total relative movement of the target during the time of flight, $Tf$, you need to multiply each of the components of relative target speed by $Tf$. Then you have the three components of the distance the target travels while the projectile is approaching:

$$Tf \times dR;\ Tf \times RdBs;\ \text{and}\ Tf \times RdE.$$

These three components are illustrated in figure 2–12. Now your problem is to find the range, $R2$, and the elevation, $E2$, of the future target position $T2$. Also you need the angle, $Dt$, measured in the slant plane between the vertical planes, and through the lines of sight to present and future target positions.

## DEFLECTION PREDICTION

The angle marked $Dt$ in figure 2–12 is not quite correct. It is measured from the vertical plane through the present LOS to a slightly slanting plane $OT2A$ through the future target position. But it is a close approximation and is the angle that is always used. Figure 2–12 greatly exaggerates the slant of plane $OT2A$, so the actual discrepancy is not large.

Angle $Dt$, in mils, then equals $\frac{AD}{OD}$. Since $OD$ is nearly equal to $R2$, we can write:

$$Dt = \frac{TfRdBs}{R2} = RdBs \times \frac{Tf}{R2}.$$

## RANGE PREDICTION

It is obvious from figure 2–12 that most of the change in range results from the range component, $TfdR$. The largest part of the range prediction, therefore, is $TfdR$, called $Rt$. In earlier rangekeepers this was the only range prediction made. Modern machines such as the Mk 1A computer, however, are more accurate.

Actually, $R2$ is larger than $OD$. One of the contributing factors is that the length $CO$ (which equals $AO$) is larger than $OD$ by the distance $AB$, caused by the range effect of deflection. This is the same quantity, $Rx$, which was computed in the Mk 8 rangekeeper by the formula

$$Rx = \frac{R2(Dt)^2}{2}.$$

In the Mk 1A computer, this formula is thrown into a slightly different form

$$Rx = \frac{Tf \times Tf \times (RdBs)^2}{2(R2)}.$$

Also, $Tf$ is roughly proportional to range; therefore, $Tf$ can be set equal to $KR2$. Then the formula becomes:

$Rx = KTf(RdBs)^2$, which is the one used in the Mk 1A.

Referring to figure 2–12 again, you can see that $R2$ is greater than $CO$ by the small distance $CT2$. This range effect of elevation is called $Re$ and is computed in exactly the same way as $Rx$; therefore:

$$Re = KTf(RdE)^2.$$

Thus, you find that the total range prediction is:

$$Rtxe = (Tf \times dR) + [KTf \times (RdBs)^2] + [KTf \times (RdE)^2]$$
$$Rtxe = Tf \times [dR + K(RdBs)^2 + K(RdE)^2]$$

The two squared terms are obtained from cams. They are added to $dR$, and the total is multiplied by time of flight in the range prediction multiplier.

## ELEVATION PREDICTION

Our final calculation is the change in elevation caused by the target moving from $T$ to $T2$, that is, to find the elevation prediction. Just as in the case of the deflection prediction, the computation is based on an approximation. The same approximation is used where it is assumed that plane $OT2A$ lies very nearly in the vertical plane through line $OT2$ (fig. 2–12).

Here you assume that the elevation of the future line of sight, $OT2$, is simply the elevation of line $OA$ plus the angle $AOT2$. The angle $AOT2$ is the biggest part of the elevation prediction. You can see from figure 2–12 that angle $AOT2$ equals $TfRdE/R2$. This is called $Vt$.

The remainder of the prediction, called the COMPLEMENTARY ERROR, is the difference in elevation between line $OA$ and the present LOS, $OT$. Actually there is no change in height in moving from point $D$ to point $A$. But remember that the deflection component causes an increase in range equal to $AB$ in figure 2–12. This increase equals $R2(Dt)^2/2$. When a target moves away from you, without changing its height, its elevation decreases. The complementary error is the amount of this change in elevation.

Figure 2–13 shows you how the complementary error is calculated. Here point $D$ has an elevation $E$ and some definite height, $H$. Point $A$ has the same height, but its range is greater by an amount $R2(Dt)^2/2$. The difference in elevation of the two points is the complementary error.

You can see that distance $AB$, figure 2–13, is nearly equal to the difference in range. Therefore, distance $DB$ equals

$$\frac{R2(Dt)^2}{2}\times\tan E2.$$

The complementary error angle, $Vx$ equals $\frac{DB}{R2'}$

therefore: $Vx=\frac{R2(Dt)^2}{2}\times\tan E2$ divided by $R2$, the $R'2$'s cancel leaving: $Vx=(Dt)^2\times\frac{1}{2}\tan E2$.

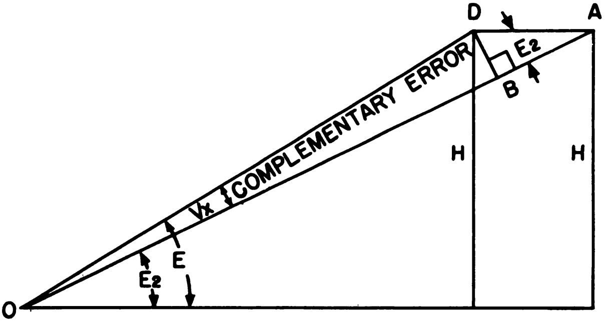

Figure 2–13.—Complementary error.

This quantity is computed in a COMPLEMENTARY ERROR CORRECTOR. The corrector is a two-cam computing multiplier, with each input slide connected to the follower of a cam. One cam computes $(Dt)^2$. The other computes $\frac{1}{2} \times \tan E2$.

## SIGHT SETTINGS

In the preceding chapter you learned to hit a stationary elevated target, making allowances for the effects of drift, wind, and *I. V.* on sight angle, sight deflection and advance range (see fig. 1–11).

In this chapter you have learned of the additional corrections to sight angle, sight deflection, and advance range which are made necessary by own ship and target motion, namely:

$$Dt = RdBs \times Tf/R2,$$

$$\begin{aligned} Vtx &= VT + Vx \\ &= RdE \times Tf + (Dt)^2 \times \tfrac{1}{2} \tan E2 \end{aligned}$$

and

$$Rtxe = Tf[dR + K(RdBs)^2 + K(RdE)^2].$$

Thus you arrive at the general formula for sight settings against any air target:

$$\begin{aligned} Ds &= Dt + Df + Dw + Dj \\ Vs &= Vf + Vtx + Vw + Vj. \end{aligned}$$

Remember that superelevation, $Vf$, is based on advance range, $R2$, which is calculated by

$$R2 = R + Rtxe + Rw + Rm + Rj$$

and on advance elevation, $E2$, which is calculated by

$$E2 = E + Vf + Vw + Vx.$$

## FUZE SETTING

Unless proximity fuzes are used, antiaircraft 3-in. or larger guns usually employ time-fuzed projectiles equipped with clockwork fuzes adjusted to explode the shell at a set time after it is fired. This is done because the chance of a direct hit on an aircraft is rather slight; but, if the projectile can be made to burst as it passes near the plane, blast and flying fragments may do almost as much damage as a direct hit.

Therefore, in addition to knowing the sight settings, knowledge of the proper time interval to set on the fuze is necessary.

If the fuze could be set at the instant the projectile is fired, you could use time of flight, $Tf$. Actually, however, the fuze is set while it is the projectile hoist on its way up from the handling room. After the setting is made, the projectile is lifted on the tray, rammed home, and the breech closed before the projectile is fired. All this takes several seconds, depending on the speed of the gun crew. This time interval is called dead time, and is represented by the symbol $Tg$.

During the dead time the range to the target is changing; therefore, at the instant the projectile is fired, the range and the time of flight are different from the value computed at the instant the fuze was set.

Consequently, when the fuze is set, you cannot use the value of $Tf$ indicated on the computer. It is necessary to use a different time of flight called $F$, corresponding to fuze range, $R3$.

In the computer, fuze range ($R3$) is determined by computing the change in advance range during dead time, $\dot{R}Tg$, and then adding $\dot{R}Tg$ to the current value of $R2$. Thus,

$$R3 = R2 + \dot{R}Tg.$$

It should be noted here that, as range changes during time of flight, and the difference in the amount of this change during $Tg$ must be accounted for, the value of $\dot{R}Tg$ derived in the computer includes a compensating factor for this difference.

The multiplication is performed in the DEAD TIME MULTIPLIER and is added to $R2$ in a differential.

Fuze setting, $F$, is obtained from the fuze ballistic computer which is driven by $R3$ and $E2$. Theoretically, the elevation input should be $E3$, corrected for change of elevation during dead time, but $E2$ is considered accurate enough.

# QUIZ

1. Into what three parts may the answers to the AA fire-control problem be resolved?
2. $E$, target elevation is measured above what plane?
3. When training a director to follow a moving target, the rate at which the director moves in azimuth is dependent upon the relative motion of what?
4. By which formula is $Xt$ (deflection component of target velocity) found?
5. How are the estimates of target course, target speed, and target rate of climb checked?
6. How many quantities are needed to define an air target's movement?
7. What quantities make up $dRh$?
8. What are the only components that have any tendency to change the bearing of the target?
9. What are the linear rates about the LOS?
10. What happens to the elevation angle when the plane comes nearer keeping the same height?
11. The output of an integrator whose carriage is positioned by inverse range and whose disk is rotated by time, is
    a. $T/cR$.
    b. $T \times cR$.
    c. $Tf/R2$.
    d. $T \times \sec E/cR$.
12. What quantities are used to make up $RdBs$?
13. The linear rates about the LOS have fixed values only as long as target motion is
    a. changing.
    b. unchanged.
    c. climbing.
    d. crossing.
14. What is the difference between advance range and fuze range?
15. Time of flight is roughly proportional to
    a. $R$.
    b. $R2$.
    c. $Rx$.
    d. $Rw$.
16. Complementary error correction is applied to
    a. elevation.
    b. train.
    c. fuze.
    d. range.

# CHAPTER 3

## THE AA FIRE-CONTROL SYSTEM—GUN AND FUZE ORDERS

The last two chapters have given you a complete picture on local control of AA fire. When the members of the gun crew are laying their own gun, only three pieces of information are required: sight angle, sight deflection, and fuze order. $Vs$ is the angle the gun must be elevated VERTICALLY above the pointer's local LOS, and $Ds$ tells how much the gun must be moved HORIZONTALLY to the right or left of the LOS. Angles $Vs$ and $Ds$ are usually small enough so that trunnion tilt introduces no serious errors.

The situation in director fire is more complicated. Just as in surface director fire, you must know the elevation of the guns PERPENDICULARLY above the deck ($E'g$), and the train of the gun IN the deck plane from the centerline of the ship ($B'gr$).

In addition, it is necessary to make parallax and roller path corrections at each gun. These will be discussed later.

In the Mk 37 dual purpose system, the director has two jobs in addition to range measurement. It must measure director train and it must also measure director elevation. To make this double measurement easier, the director optics are stabilized in cross level. This means that the director telescopes elevate in a vertical plane.

You remember that the pointer's or leveler's telescope in a surface director elevates in the same manner as the guns. That is, the elevation prism of the telescope turns about trunnions which are always parallel to the deck. The LOS elevates in a plane perpendicular to the deck. In surface fire, where the LOS is always horizontal, this causes no trouble. However, let's consider the action of this sight if it is used on an elevated target.

Imagine that the deck is level. The director trains from the bow of the ship around to a point vertically under the target. Then the telescope elevates vertically to the target. But now suppose that the ship rolls so that the gun and telescope trunnions are tilted. The telescope LOS will swing far to one side. In order to get back on target, the trainer will have to train the director to a point perpendicularly under the target. As the ship reverses its roll, he will have to train back. The value of director train will be changing continually as the trunnions tilt.

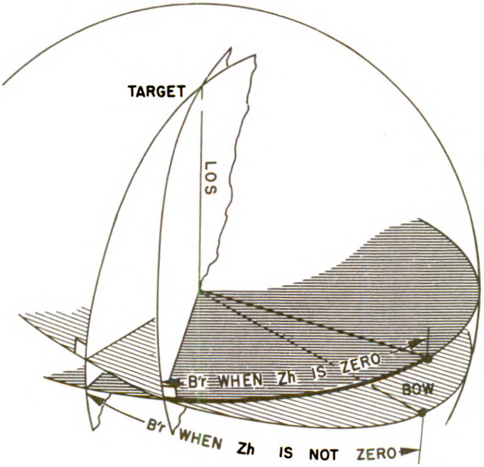

**Figure 3–1.—Angles measured by a director which is not stabilized.**

The spherical diagram, figure 3–1, shows you the basic difficulty. You are measuring the angle *B'r*, in the deck plane, between the centerline of the ship and a plane through the LOS perpendicular to the deck. As the tilt of the deck changes, this plane keeps moving—and the value of director train changes as it moves.

This difficulty is avoided, however, in the design of an AA director such as the Mk 37. The telescopes are mounted so that they may be rolled on bearings about their own axis within the telescope housing. An input of cross-level from the stable element turns each telescope, keeping the prism trunnions horizontal at all times. Thus the telescope LOS elevates and depresses in a vertical plane through the target, regardless of how the ship rolls. As a result, director train is always measured from the bow of the ship to one par-

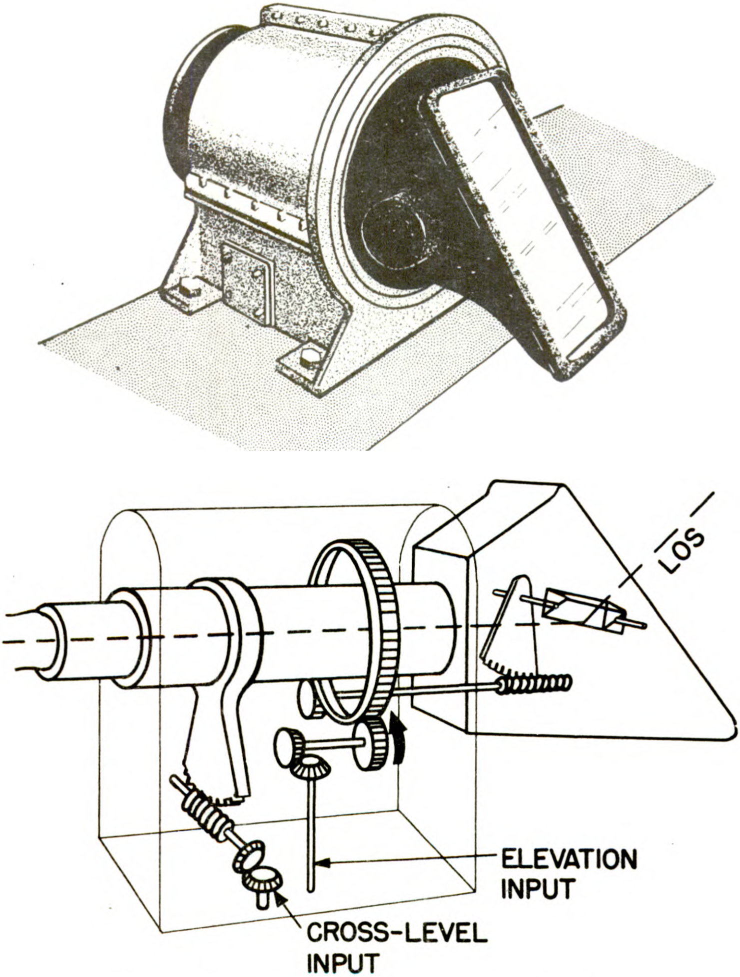

**Figure 3–2.—Telescope used in a stabilized director.**

ticular plane—the vertical plane through the LOS to the target. This value of director train is called $B'r$ instead of $B'r'$. It is true, however, that changes in cross level will still make a small difference in the value of director train, because director train is measured in the deck plane, and the deck plane moves as cross level changes. This is the same effect as $jB'r$ in surface fire. But large changes in train are prevented by stabilizing the director.

Figure 3–2 shows the outside of the telescope, and its housing, as well as a schematic view of the way it operates. Notice particularly how the elevation input works. The elevation gearing drives an idler ring gear which, in turn, drives the gearing to the prism. This raises another design problem. You can see that changes in cross level will introduce false inputs of elevation. For, as the telescope rotates, the gearing from the idler gear to the prism will walk around the ring, rotating as it does so. The gear-

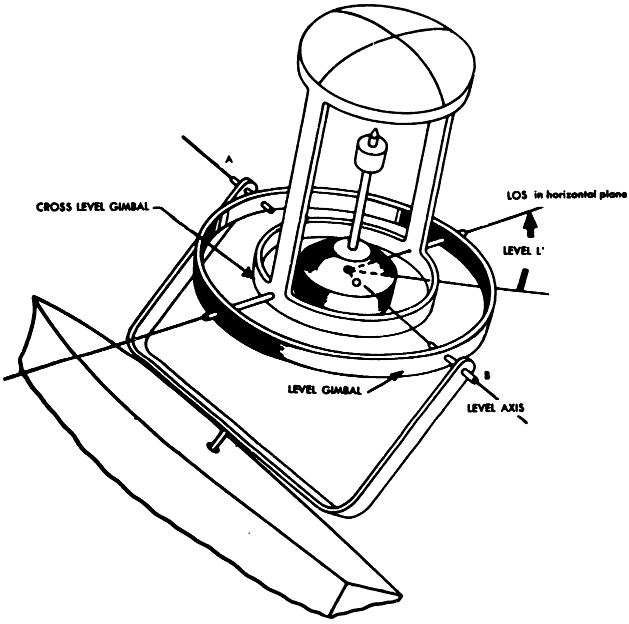

Figure 3–3.—The stable vertical.

ing ratios are such that the false elevation input, caused by the effect of cross level, can be removed by subtracting one-thirtieth of cross level from the elevation input.

Stabilizing the director has one other important advantage. It gives you a direct measured value of target elevation, $E$. Target elevation is the angle, measured in a vertical plane, between the LOS and the horizontal. With a stabilized director, director elevation $Eb$ is the angle measured in a vertical plane between the LOS and the deck. Thus the only difference between $E$ and $Eb$ is the angle between the deck and the horizontal-level angle, $L$. Therefore:

$$Eb = E + L.$$

Since $E$ and $Eb$ are angles in a vertical plane, $L$ must be measured in the same vertical plane. The stable vertical used in surface fire, you remember, measures level, $L'$, in the plane perpendicular to the deck. Figure 3–3 shows why this is so. The outer gimbal of the stable vertical has its axis at right angles to the LOS. Movement of this gimbal, therefore, measures level angle. And since the outer gimbal axis is always parallel to the deck, it measures level in the plane perpendicular to the deck. The inner gimbal, which measures cross level, always has its axis horizontal because it is attached to the outer gimbal which is kept horizontal by the level follow-up.

If the sensitive element is turned 90° from its position in figure 3–3, the axis of the outer gimbal will be headed along the LOS as in figure 3–4. Thus the outer gimbal measures cross level in the deck plane and, at the same time, keeps the axis of the inner gimbal horizontal. The inner gimbal, therefore, measures level in a vertical plane. This value of level is called $L$ instead of $L'$.

A stabilizing unit designed to measure level with its inner gimbal is called a stable element instead of a stable vertical. The angles measured by the stable element are illustrated in the spherical diagram of figure 3–5. Notice that $L$ is measured in the vertical plane containing the LOS. $Zd$ is the angle of roll about the line which is the intersection of the deck plane with the vertical plane through the LOS.

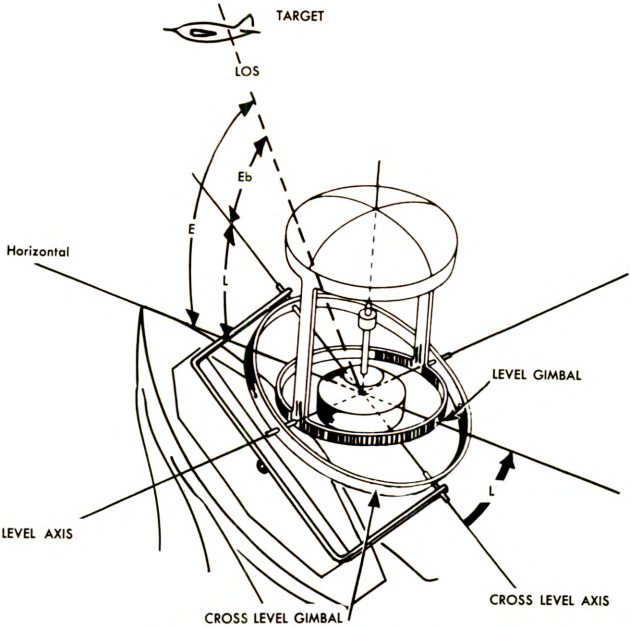

Figure 3–4.—The stable element.

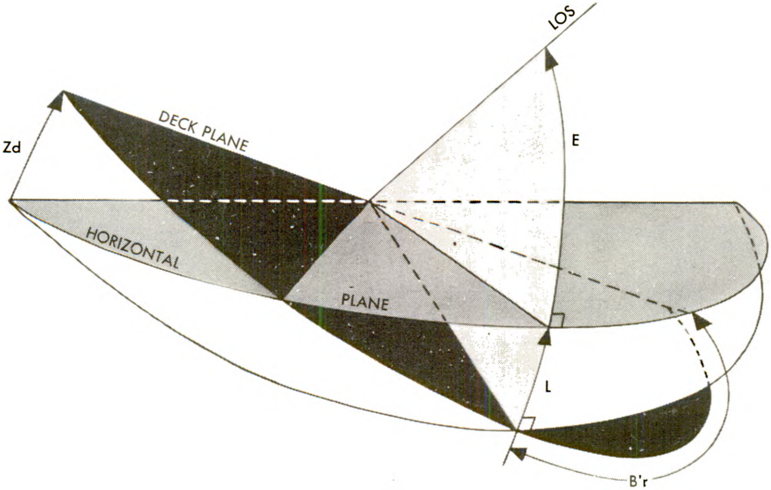

Figure 3–5.—*L* and *Zd* as measured by the stable element.

## COMPUTING GUN ORDERS

You are now ready to calculate gun orders. You know $Vs$ and $Ds$; and have $Eb$, $B'r$, $L$ and $Zd$ from the director and stable element.

Consider first the simple case when the deck is level as illustrated by the spherical diagram of figure 3–6. In figure 3–6, the partial elevation prediction, $Vtw$, is added to $E$ in the vertical plane through the LOS. A slant plane is then added at right angles to plane $A$ at an angle of $E+Vtw$ above the horizontal plane. Sight deflection, $Ds$, is measured in this slant plane.

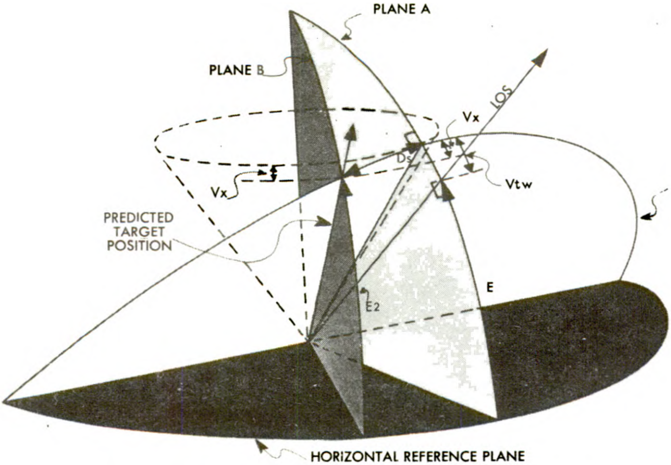

**Figure 3–6.—Establishing the plane containing the LOF.**

One side of $Ds$ lies in the vertical plane containing the LOS. Another vertical plane, plane $B$, passes through the other side of angle $Ds$. This new vertical plane is the plane which will contain the LOF.

Notice that the angle formed by the slant plane and the horizontal plane, measured in the vertical plane $B$, is called $E2$, predicted target elevation. $E2$, you remember from the preceding chapter, was used in the calculation of time of flight and superelevation. $E2$ is equal to $E+Vtw-Vx$ (fig. 3–6).

$Vtw-Vx$ is equal to the elevation prediction, $V$. Predicted target elevation is, therefore:

$$E2=E+(Vtw-Vx)$$
$$E2=E+V.$$

When we previously discussed the complementary error correction, $Vx$, it was shown in a two-dimensional diagram. Now you can see the complementary error correction on the spherical diagram of the AA problem.

$E2$ is used to compute superelevation which is a part of sight angle. $E2$, therefore, must be measured in coordinates which correspond with gun train and gun elevation. Now the guns, in moving from $E$ to $E2$, cannot move through the slant plane containing $Ds$. Instead, they sweep out an inverted cone whose base is always parallel to the deck plane (see fig. 3–6). Thus if the gun were trained from position $E+Vtw$ to the vertical plane containing $E2$, it would be elevated above $E2$ by the angle $Vx$. It is necessary, therefore, to subtract $Vx$ from $E+Vtw$.

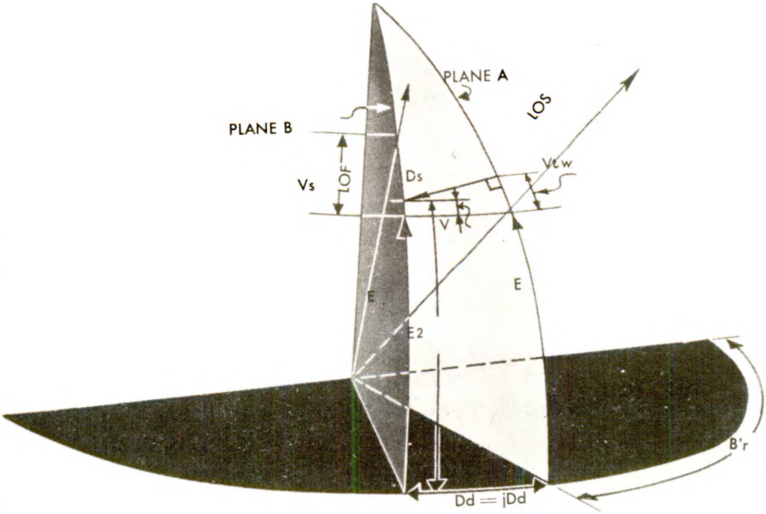

Figure 3–7.—Establishing the plane containing the LOF.

The LOF is now obtained by transferring angle $E$ from plane $A$ to plane $B$, and adding $Vs$ to angle $E$ in this plane (fig. 3–7). Since the deck plane lies in the horizontal reference plane, $E$ is equal to director elevation; and gun elevation order becomes:

$$E'g = Eb + Vs.$$

In a similar manner gun train order, $B'gr$, is the sum of director train and total deck deflection, $Dd$:

$$B'gr = B'r + Dd.$$

Now what happens when the ship rolls and pitches? The total deck deflection, $Dd$, is more than the projection of angle $Ds$ onto the deck plane. It is the sum of corrections for level, cross level, and trunnion tilt as well.

For convenience, therefore, $Dd$ is divided into two parts: $Dz$, the train correction for trunnion tilt, and $jDd$, the projection of $Ds$ onto the deck plane. $Dz$ and $jDd$ are then added in a differential and their sum is $Dd$. Gun train order, therefore, is:

$$B'gr = B'r + (jDd + Dz),$$
$$B'gr = B'r + Dd.$$

Since trunnion tilt also affects gun elevation order, a correction to gun elevation order for the effects of trunnion tilt must be added to $Eb + Vs$:

$$E'g = Eb + Vs + Vz.$$

## TRUNNION TILT

A basic explanation of the effects of trunnion tilt is given in the three drawings of figure 3–8. In figure 3–8a the deck is level and gun orders have been computed to score a hit. Now the ship rolls. Since the gun can only elevate perpendicularly to the deck, the bore axis of the gun swings off to the right, as is shown in figure 3–8b. The gun, therefore, must be trained uphill to get back on target. In so doing, naturally, you raise the gun too high—figure 3–8c—and have to lower it to compensate.

The angles through which the gun is trained and depressed to bring the axis of the gun back into coincidence with the LOF are called *Dz*, the train correction due to cross level, and *Vz*, the elevation correction due to cross level. See figure 3–8c.

It is difficult, in a spherical diagram, to separate the trunnion tilt and partial deck deflection. For convenience of illustration in figure 3–9, therefore, it has been assumed that *Vs* and *Ds* are zero and that the LOF and LOS are coincidental. You can see that, for the same value of cross level, *Dz* and *Vz* increase with gun elevation.

If *Vz* and *Dz* were calculated exactly, an immense amount of equipment would be necessary. However, the design engineers, through tests, arrived at a pair of empirical formulas which produce satisfactory values of *Dz* and *Vz* with a minimum of basic mechanisms.

In the Mk 1A computer, *Dz* is calculated from—

$$Dz = f\ (Eb + Vs) \times \sin 2Zd.$$

And *Vz* is computed from—

$$Vz = KZd^2 \tan(Eb + Vs) + K1ZdDs.$$

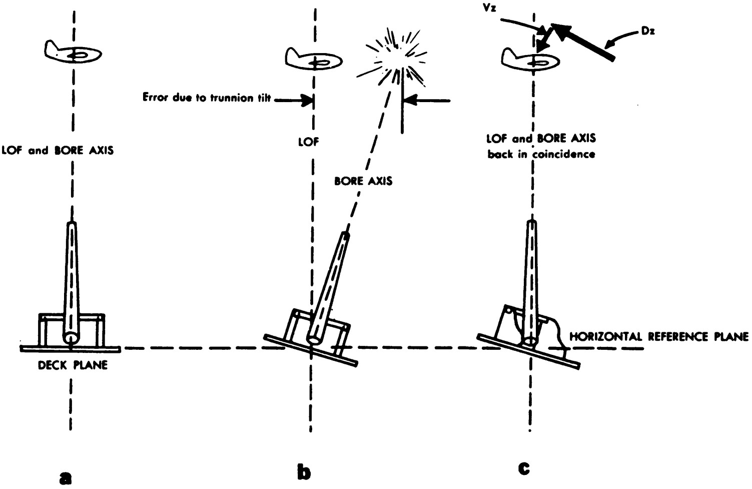
LOF and BORE AXIS
DECK PLANE
Error due to trunnion tilt
LOF
BORE AXIS
Vz
Dz
LOF and BORE AXIS back in coincidence
HORIZONTAL REFERENCE PLANE
a
b
c

**Figure 3–8.—The effects of trunnion tilt.**

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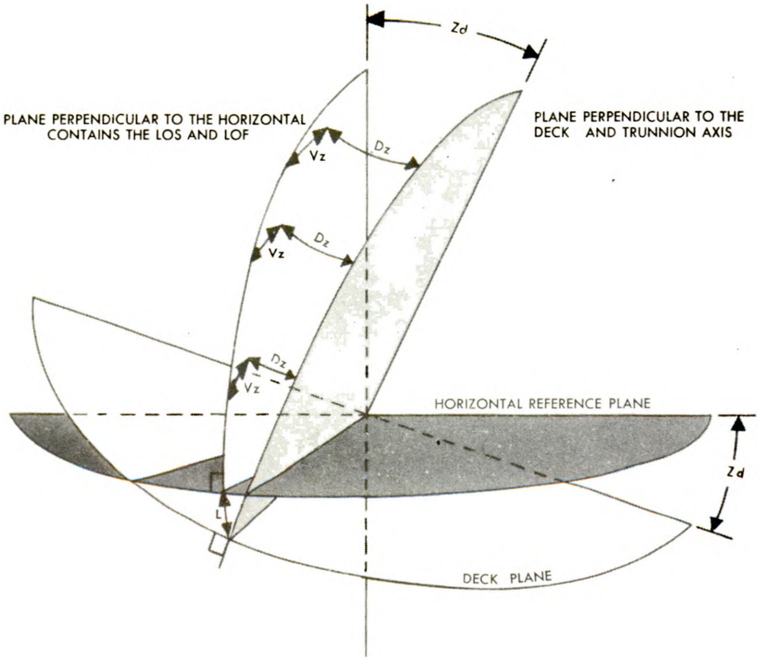

Zd
PLANE PERPENDICULAR TO THE HORIZONTAL CONTAINS THE LOS AND LOF
PLANE PERPENDICULAR TO THE DECK AND TRUNNION AXIS
Vz
Dz
Vz
Dz
Dz
Vz
HORIZONTAL REFERENCE PLANE
Zd
L
DECK PLANE

**Figure 3–9.—Trunnion tilt corrections increase with elevation.**

Thus $Dz$ is the output of a component solver with a sine rack only. And $Vz$ is the sum of the products of a double cam computing multiplier ($KZd^2\tan(Eb+Vs)$) and another multiplier ($K1ZdDs$).

## *jDd*, PARTIAL DECK DEFLECTION

You already know that $jDd$ is the projection of $Ds$ onto the deck plane. When level and cross-level are zero, $jDd$ is the only correction and is, therefore, equal to $Dd$ (fig. 3–7).

When level and cross level are present, gun train order is the sum of $B'r+jDd+Dz$ (fig. 3–10). Since the deck is now slanting, $jDd$ is more than the projection of sight angle on the horizontal reference plane—it must be corrected for the effects of level and cross level as well.

Here again an approximate formula was derived which will produce satisfactory results as long as $L$ and $Zd$ are smaller than 15°, and $E2$ is less than 70°:

$\sin jDd = Ds \sec (E2+L-KZd^2)$, which can be rewritten:

$jDd = \sin^{-1} [Ds \sec (E2+L-KZd^2)]$, where the $\sin^{-1}$ means the angle whose sin is expressed by the value inside the brackets. For example,

$$\sin^{-1} [0.5] = 30°.$$

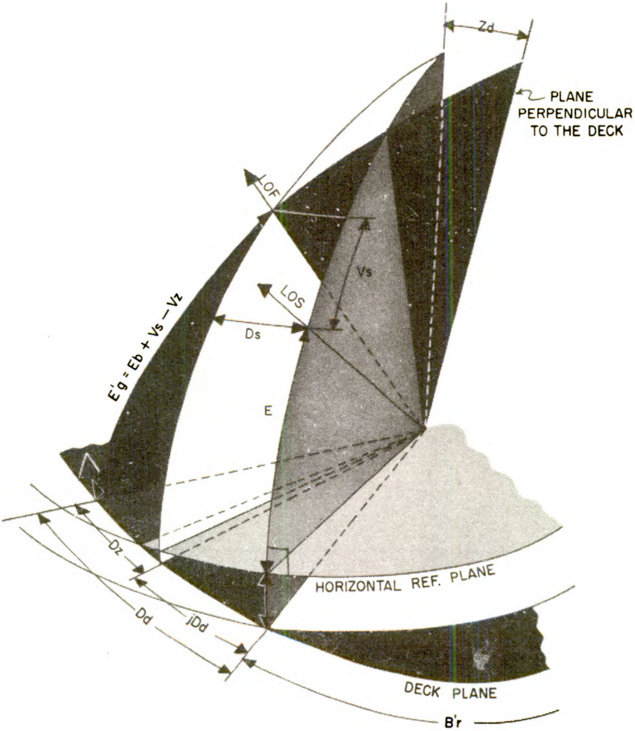


Figure 3–10.—Gun orders on a rolling deck.

## FUZE ORDERS

Fuze orders in director control are the same as those in local control.

## EFFECTS OF PARALLAX

Thus far we have assumed that the director and guns were located at the same theoretical point on the ship. Just as in surface fire, however, you have to make allowances for the distance between guns and directors; and in addition, on

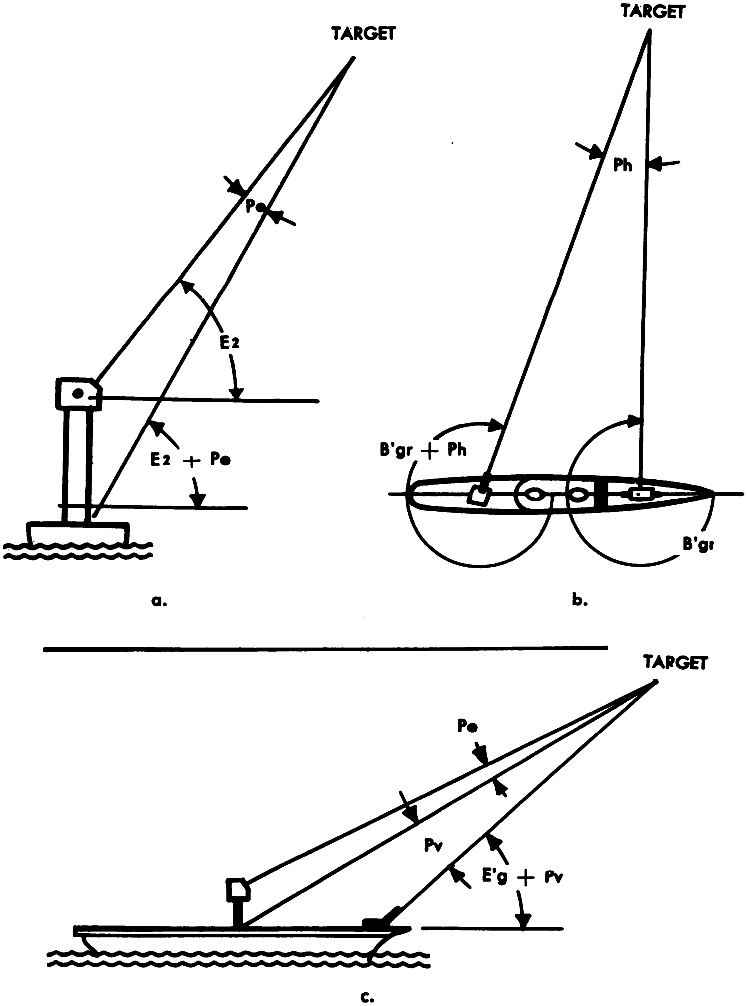


Figure 3–11.—The parallax corrections.

ships with more than one director, you must also calculate parallax from a central reference point.

The director is separated from the guns both vertically and horizontally; therefore, three types of parallax corrections are necessary. *Pe*, the vertical parallax correction and *Ph*, the horizontal base correction are common to all batteries. *Pv*, the elevation parallax correction due to a horizontal base, however, is computed only for carriers where the distance between the director and the forward and aft single mounts is large. (See fig. 3–11.)

On most ships a majority of the guns are the same height. Therefore, the vertical distance between the director and guns, called *bv*, is assumed to be a constant—usually 10 yards. Thus the parallax effect of a vertical base is included directly in gun elevation order.

Since our problem is to correct gun orders to the predicted position of the target, the corrections are based on *E*2, *R*2, and *B′gr*.

Also, the distance between guns is smaller in most AA batteries than in main batteries. AA fire, moreover, is

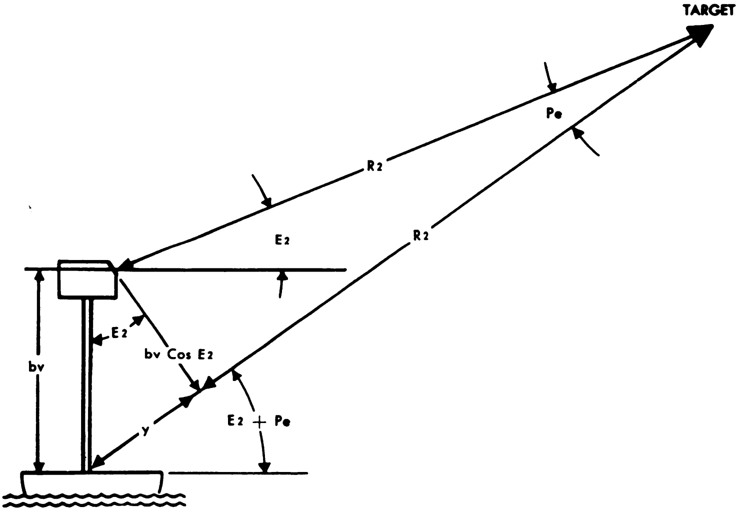


Figure 3–12.—Parallax due to a vertical base.

always less accurate than surface. The range effect, therefore, of the horizontal and vertical displacement of the guns and mounts is neglected. It is assumed that $R2$ has the same value, whether measured from the director, from a point at the base of the director, or from any gun.

As you can see from figure 3–12, it is very nearly true that:

$$Pe=\frac{R2-y}{bv \cos E2}.$$

Since $R2—y$ is approximately equal to $R2$

$$Pe=\frac{R2}{bv \cos E2}.$$

This formula is slightly in error when $L$ is not zero, but for practical purposes, *Pe* depends upon advance range and predicted elevation. Therefore, it can be computed by means of a three-dimensional cam driven by $R2$ and $E2$. In the Mk 1A computer *Pe* is combined with superelevation and both functions are calculated on one cam. The output of the cam is $(Vf+Pe)$. Thus *Pe* becomes a part of *Vs* and therefore of gun elevation order.

The horizontal difference between the guns and director or reference point is different for each gun. Consequently, the resulting parallax effect cannot be included in gun orders. The formulas for parallax in AA fire are more complicated than in surface fire. It is not practical, therefore, to compute parallax separately at each gun.

Instead, values of parallax corresponding to a base length of 100 yards are computed in plot. These values are transmitted to each mount and each director (if there is more than one). There 100 yards are driven through gearing which multiplies them by the actual base length divided by 100—thus giving the value of parallax at each gun or director.

Figure 3–13 is a plan view of a typical AA situation. From this top view you can see that the tangent of *Ph* is nearly equal to *bh* sin *B'gr* divided by the projection of slant range on the deck plane. That is—

$$\tan Ph = \frac{bh \sin B'gr}{R2 \cos (E2+L) - y}.$$

Then, since $y$ is very small,

$$\tan Ph = \frac{bh \sin B'gr}{R2 \cos (E2+L)}.$$

For small angles the tangent of the angle is very nearly equal to the value of the angle in mils, therefore:

$$Ph \text{ (in minutes of arc)} = \frac{bh \sin B'gr}{R2 \cos (E2+L)} \times K,$$

where $K$ is equal to 3.43 minutes of arc per mil. Therefore, for a 100-yard base length:

$$Ph = K \times 100 \times \frac{1}{R2} \sin B'gr \times \sec (E2+L).$$

The term, $\frac{1}{R2} \sin B'gr$, is computed in a special component solver. Gun train order is usually the angular input. But the speed cam is cut in such a way that, when the cam is driven by $R2$, the speed pin moves a distance proportional to inverse range. The output of this component solver goes to a multiplier, whose other input is the output of a secant cam driven by $E2+L$. $K$ is taken into account by graduating the $Ph$ dial in degrees instead of mils.

There are certain installations where it is necessary to use $B'r$ instead of $B'gr$ as the angular input to the parallax computer. As you remember, from your study of the surface problem, the parallax difference between the directors in a multiple director installation is computed from a mean reference point. The reference point is illustrated on the plan views of the ships in figure 3–14.

In a single director installation the director is, of course, the reference point, and $B'gr$ is used to compute $Ph$. Consider, however, the plan view of figure 3–14e. Theoretically the parallax between directors and the reference point should be based on $B'r$ and the parallax between guns and the reference point should be based on $B'gr$.

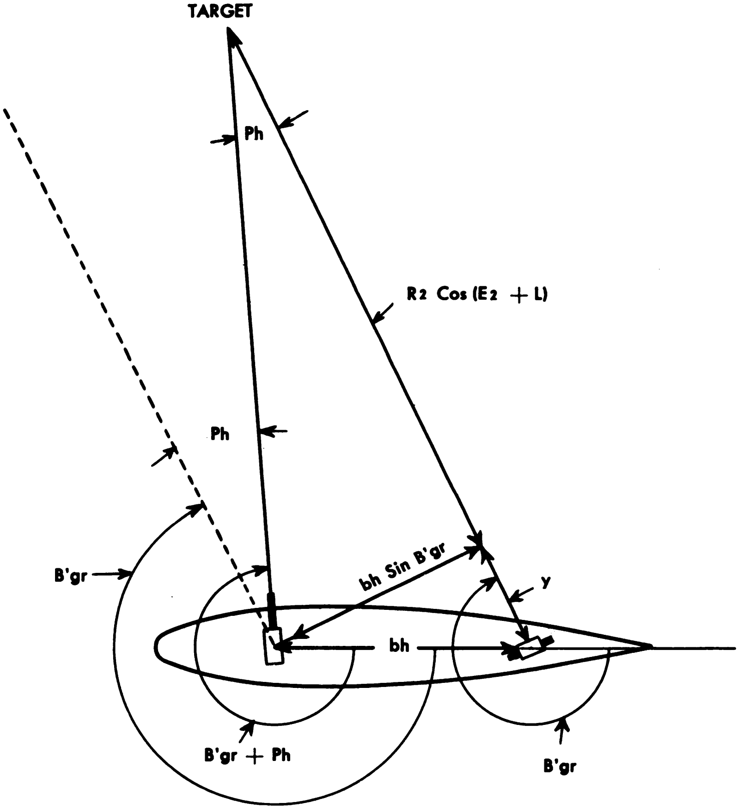


Figure 3—13.—Parallax effect on a horizontal base on B'gr.

At the average firing range, the difference is small between *Ph* based on *B′r*, and *Ph* computed from *B′gr*. Therefore, the same value of horizontal parallax is used for both director and guns.

Even though the error between the two values of *Ph* is small, the error can be further reduced by selecting either *B′r* or *B′gr* for the angular input to the parallax computer. It depends upon the type of installation.

When the directors are farther from the reference point than the guns, *B′r* is used instead of *B′gr* to compute *Ph*.

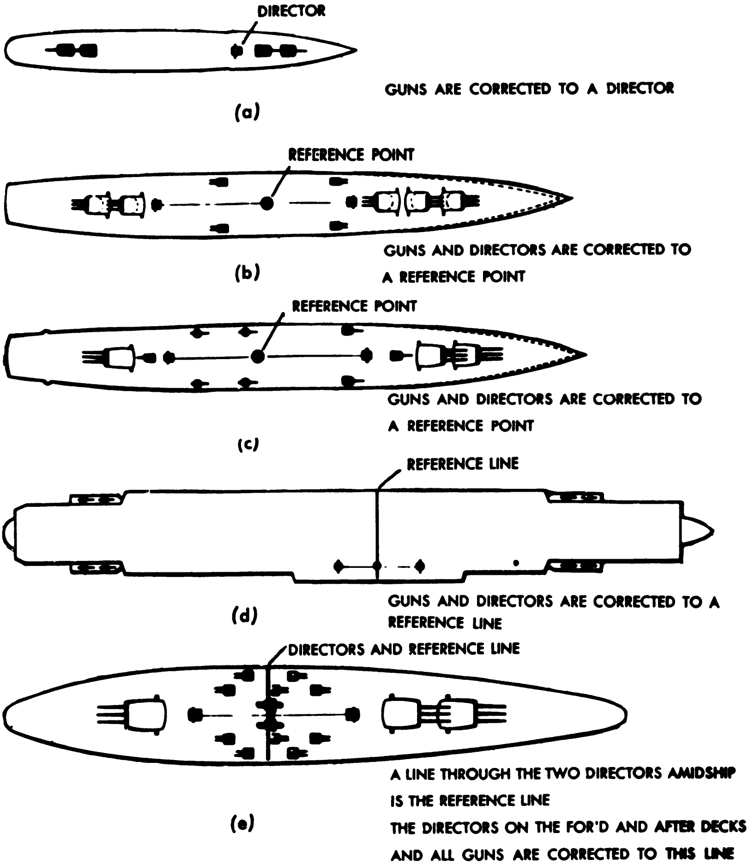

DIRECTOR
GUNS ARE CORRECTED TO A DIRECTOR
(a)
REFERENCE POINT
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE POINT
(b)
REFERENCE POINT
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE POINT
(c)
REFERENCE LINE
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE LINE
(d)
DIRECTORS AND REFERENCE LINE
A LINE THROUGH THE TWO DIRECTORS AMIDSHIP IS THE REFERENCE LINE
THE DIRECTORS ON THE FOR'D AND AFTER DECKS AND ALL GUNS ARE CORRECTED TO THIS LINE
(e)

**Figure 3–14.—Parallax is computed from a mean reference point.**

In figure 3–15, $B'r$ is used in the computation of horizontal parallax; therefore, there is a small error in the angle $Ph$, because $B'gr$ is separated from $B'r$ by the angle $Dd$.

However, $Ph$ is computed on a 100-yard base; the guns and directors use a fraction directly proportional to their distance from the reference point. Thus, while $Ph$ based on $B'r$ is slightly in error for gun train, each gun uses only a small fraction of the quantity and the error is reduced by the value of the fraction. Thus (fig. 3–15) corrected gun train,

$B'gr+\frac{Ph\times 10}{100}$ is only in error by $\frac{1}{10}$ of the originally small error in *Ph*. And director train, corrected for this value of parallax is the true value of *B′r*.

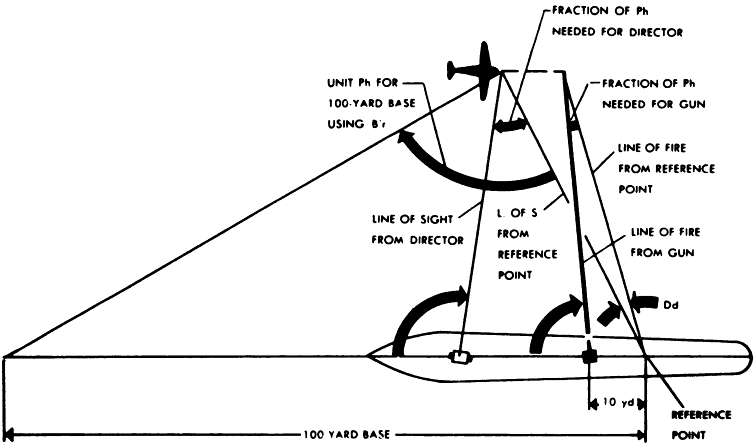


**Figure 3–15.—*Ph* is computed from *B′r*.**

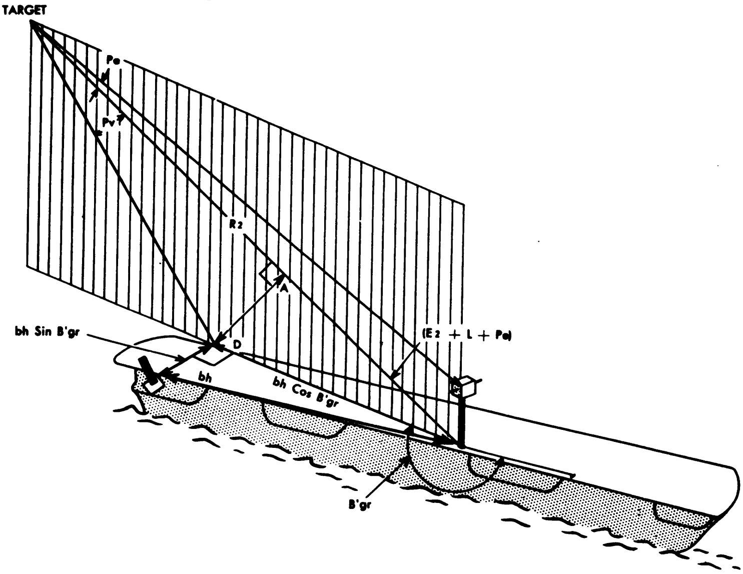


**Figure 3–16.—Elevation parallax.**

Referring again to figure 3–11, you can see that vertical parallax, $Pv$, due to a horizontal base is a large quantity on some carrier installations—the single mounts are a great distance from the directors.

In figure 3–16, you can see that the vertical parallax effect of a horizontal base is distance $AD$ divided by advance range. And, neglecting $Pe$, $AD$ equal $bh$ cos $B'gr$ sin $(E2+L)$. So for a 100-yard base:

$$Pv = K \times 100 \times \frac{1}{R2} \cos B'gr \sin (E2+L).$$

The first term is obtained from the cosine slide of the same component solver used in calculating $Ph$. The term, sin $(E2+L)$ is obtained from a cam, and both quantities are driven into a multiplier. $K$ is the same as in $Ph$.

Roller path inclination is handled in the same way as in surface fire—computed by component solvers at the guns and the directors.

## QUIZ

1. Because the director optics are stabilized in cross-level, the elevation prisms of the director telescopes elevate in the
   a. deck plane.
   b. horizontal plane.
   c. vertical plane.
   d. standard reference plane.
2. The angle $B'r$ is measured between the centerline of the ship and
   a. a plane through the LOF perpendicular to the deck.
   b. a plane through the LOS perpendicular to the deck.
   c. a plane through the LOS perpendicular to the reference plane.
   d. the intersection of the vertical plane containing the LOS with the deck plane.
3. The angle between $E$ and $Eb$ is
   a. $L$.
   b. $L + \frac{Zd}{30}$.
   c. $L' + \frac{Zd}{30}$.
   d. $L'$.

4. What is the major difference between a stable vertical and stable element?
5. The quantity $E2$ is used only in the
   a. guns.
   b. director.
   c. computer.
   d. stable element.
6. What corrections to gun orders are necessary because of trunnion tilt?
7. $jDd$ is the projection of $Ds$ onto the
   a. deck plane.
   b. horizontal plane.
   c. reference plane.
   d. vertical plane.
8. The three types of parallax are
   a. $Pe$, $bh$, and $bv$.
   b. $Pe$, $Pv$, and $Ph$.
   c. $Po$, $Pv$, and $Ph$.
   d. $Pr$, $Ph$, and $Pe$.
9. What is the difference between the angles $E2$ and $E+Vtw$?

# CHAPTER 4

## THE AA FIRE-CONTROL SYSTEM—RATE CONTROL

The comparison of generated and observed rates of director movement used to compute accurate values of target motion is known as rate control. The necessity for more rapid rate control solutions and greater flexibility of operation is met by a new type of rate control system in the Computer Mk 1A. The target vector rate control system of Computer Mk 1A is, in general, similar to the rate control system of Computer Mk 1. The methods of rate control for the Mk 1A are the same as those for the Mk 1 except for the following three principal differences.

1. Resolution of horizontal rate corrections is taken relative to the target vector, rather than to compass directions in the Mk 1A.
2. Inclusion of a sensitivity control mechanism in the elevation and bearing networks of Computer Mk 1A.
3. The use of additional automatic tracking controls in Computer Mk 1A.

Because of these differences, the target vector rate control system improves the performance of the computer by providing a faster rate solution. Converting to the target vector method of rate control makes it possible to operate the computer in automatic control against high speed (15 knots or over) surface targets by eliminating the low speed limitations imposed by the target vector solver. Introduction of the control mentioned in item three simplifies the task of the computer operating crew during target acquisition.

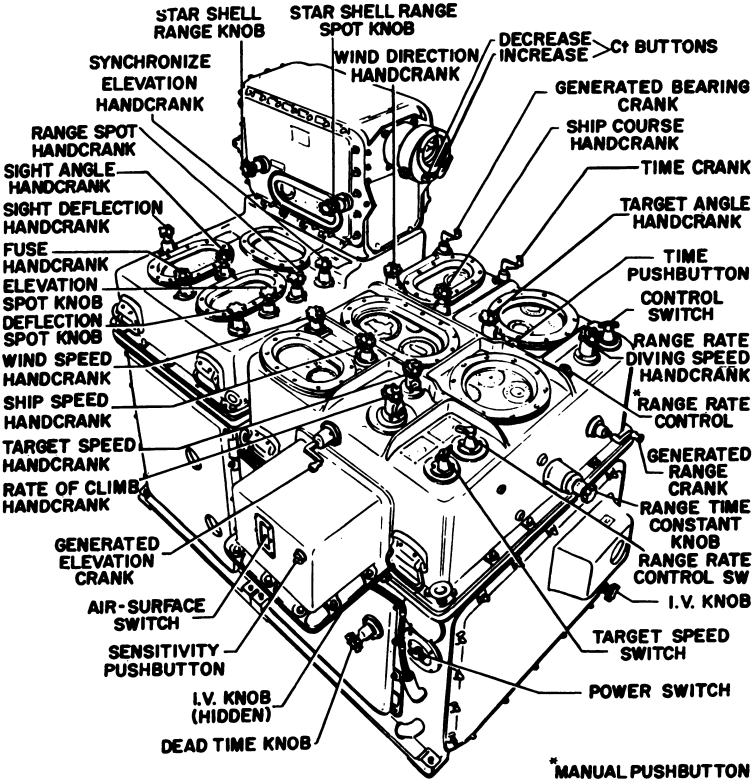


**Figure 4–1.—Computer Mk 1A—operating controls.**

## HANDCRANKS AND DIALS USED IN RATE CONTROL

The dials, handcranks, and switches used for rate control in Computer Mk 1A are shown in figure 4–1. These differ from those of Computer Mk 1 in the following respects:

a. Relocation of the *dH* handcrank.

b. Addition of the Air-Surface selector switch.

c. Addition of the sensitivity push button.

d. Addition of the time motor push button, and removal of the time motor switch.

In Computer Mk 1A the comparison of observed and generated values of range, elevation, and bearing is the same as described in OP 1064 for Computer Mk 1.

## THE RATE CONTROL COMPUTING MECHANISM

The mechanisms of the rate control group of the Mk 1A (see figs. 4–2 and 4–3) are the same as those in the Mk 1, with the following exceptions:

1. There is no vector solver.
2. Mechanism for controlling sensitivity of the elevation and bearing networks (fig. 4–3) has been added. This consists of the following separate mechanisms: two 3-inch disk integrators, a single-speed rate control range receiver, a time constant control transmitter, and time delay relay.
3. A follow-up for the *jHc* output has been added. This is designated as the *dH* follow-up.

## THE RATE ERROR CORRECTION MEASURING NETWORK

In this network the differences between the generated and observed changes in range, bearing, and elevation are measured, and the corrections to the target motion rates to be applied in the computer are determined. Measurement of the differences is accomplished in the same manner and by the same mechanisms in both Computer Mk 1 and Computer Mk 1A. Determination of the rate control rate corrections (*jEc* in elevation, *jBc* in bearing) is different in Computers Mk 1 and Mk 1A. The measured elevation rate error (*jE*) and the measured bearing rate error (*jBr*), being angular quantities, are converted into linear quantities. In Computer Mk 1A this is accomplished by means of the elevation correction integrator and the bearing correction integrator, which are shown in figure 4–3. It can be seen that the integrator disks are driven by the angular measurements, while the carriages are positioned by range. Thus the roller outputs of the integrators are products of the angular rate errors and range. The linear rate errors corresponding to a given angular rate error is proportional to range, therefore the outputs of the integrators represent the linear rate error, *jEc* for elevation, *jBc* for bearing. These outputs are the rate error corrections set into the component integrators of the computer. For purposes of stability, it is desirable to make these corrections correspondingly less than the measured errors. This is accomplished by introducing less-than-unity

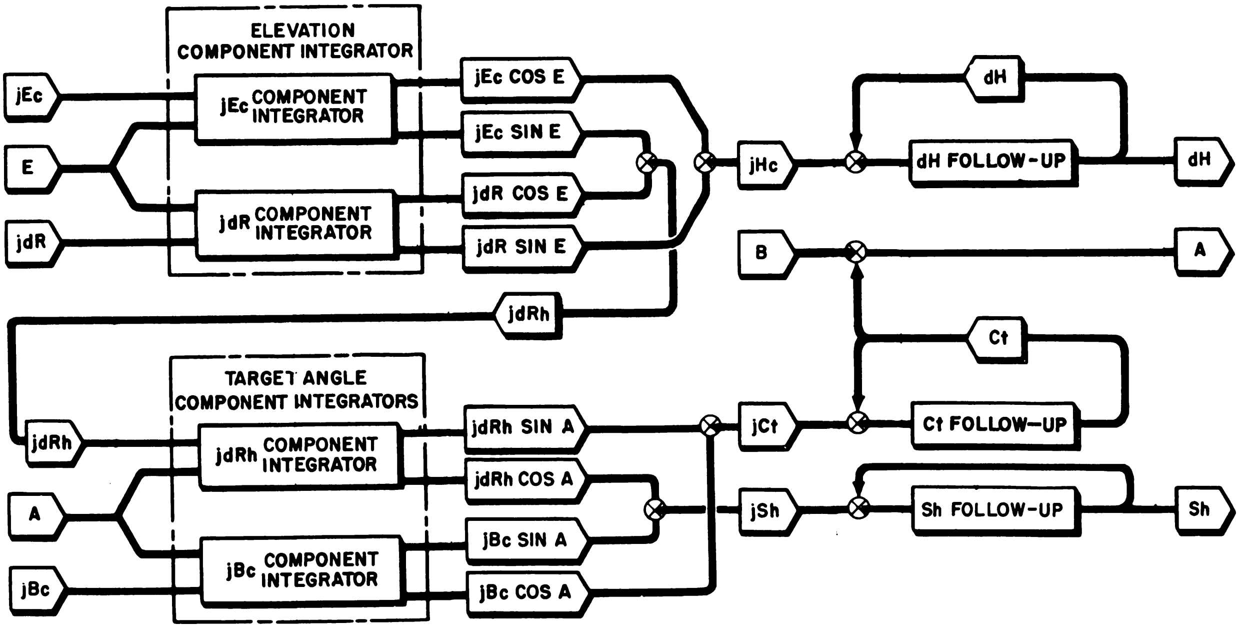


Figure 4–2.—Target motion correction computing network.

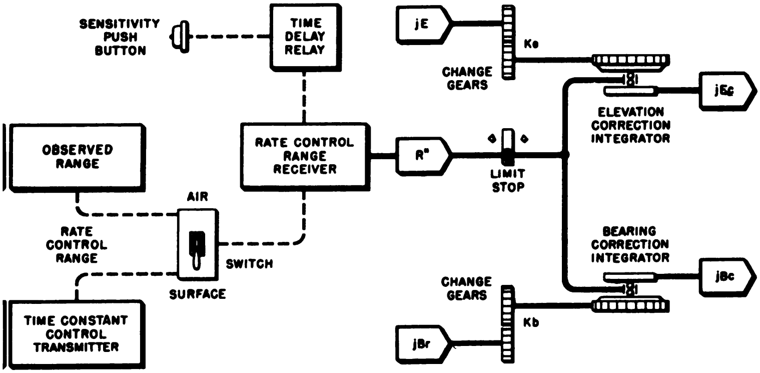


Figure 4–3.—Sensitivity control system.

gear ratios, *Ke* and *Kb*, in the *jE* and *jBr* shaft line inputs to the correction integrator disks. This affects the time constant of the instrument (the time required to reduce the error to 37% of its original value) as will be discussed in detail later. Change gears are provided so that the ratios may be conveniently altered if it is found desirable to do so.

Range rate errors are measured and corrected in Computer Mk 1A in exactly the same manner as in Computer Mk 1; see OP 1064.

## TARGET MOTION CORRECTION COMPUTING NETWORK

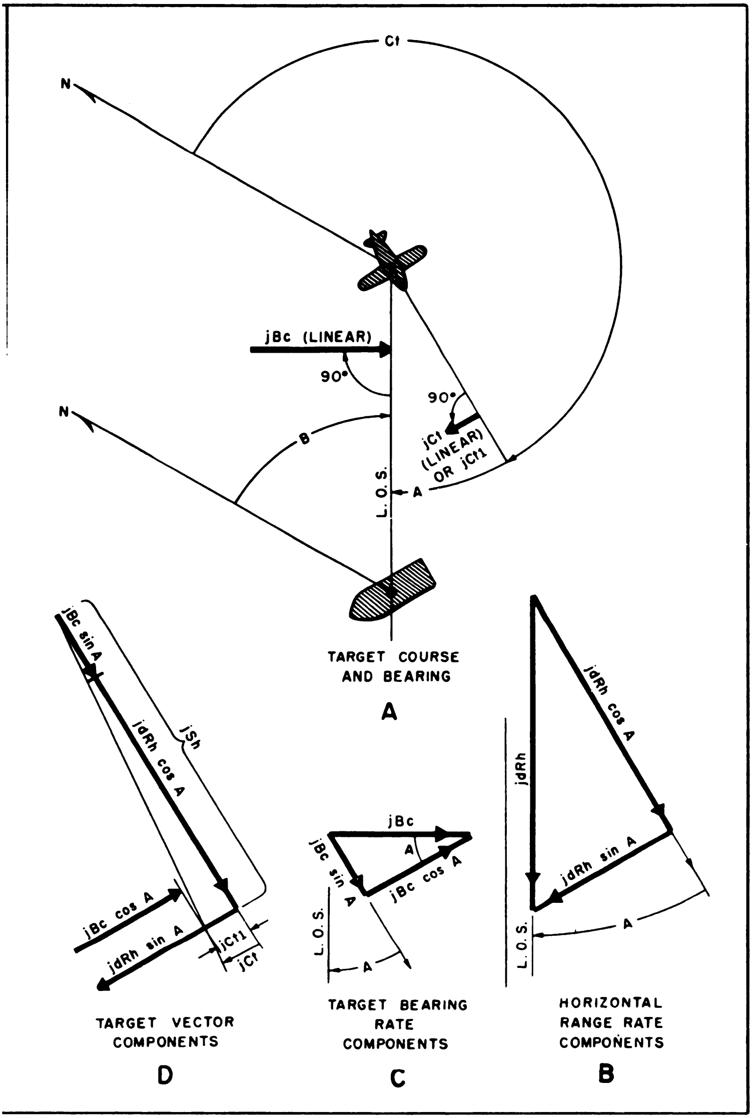
Because of the method employed for computing relative motion rates in the Computer Mk 1A, neither the range rate correction (*jdR*), the elevation rate correction (*jEc*), nor the bearing rate correction (*jBc*) can be added directly to the respective computed rates of *dR*, *RdE*, and *RdBs*. They must be resolved and applied as corrective changes to horizontal target speed (*Sh*), target angle (*A*), and rate of climb (*dH*). These corrective changes are obtained by resolving the rate corrections *jdR*, *jEc*, and *jBc* into horizontal and vertical components in the target motion correction computing network. This network consists of the elevation component integrators, the target angle component integrators, and related gearing and follow-ups. (See fig.

4–2.) These basic mechanisms are the same as the corresponding ones in Computer Mk 1.

The elevation component integrators resolve range rate correction (*jdR*) and elevation rate correction (*jEc*) into horizontal and vertical components, as described in OP 1064. The horizontal component (*jdRh*) is applied as an input to the target angle component integrators (see fig. 4–2). The vertical component (*jHc*) is applied as a correction to *dH* at the *dH* follow-up. This follow-up is of the limited error type like the *jSh* and *jCt* follow-ups. In this type of follow-up, the follow-up differential spider shaft operates a limit stop, and there is a friction drive in the input line. The arrangement is such that if either the *jHc* or the *dH* line is rotated while the follow-up is de-energized, a limit of the stop is soon reached after which the friction drive permits continued rotation of either line. When energized, the follow-up needs to drive but a short amount to synchronism, after which it will amplify any further input of *jHc*. This avoids having inputs that were made while the follow-up was de-energized upset by the follow-up running to synchronism when power is applied.

In Computer Mk 1A, bearing rate correction (*jBc*) and horizontal range rate correction (*jdRh*) are resolved into horizontal components taken with respect to the vertical plane through the target path (see fig. 4–4 A & B), rather than with respect to a North-South line as in Computer Mk 1. Therefore, target angle (*A*) instead of target bearing (*B*) is used as an input to the target angle component integrators. The outputs from this component integrator group are *jSh*, the correction to target speed, and *jCt*1, the linear correction to the direction of target motion. Because these outputs are taken with respect to the line of target motion, the cumbersome vector solver used in Computer Mk 1 can be eliminated. One output, *jSh*, is applied to horizontal target speed (*Sh*) at the *Sh* follow-up. The other output, *jCt*1, is converted to the angular quantity *jCt*1 in the instrument gearing and applied to target angle (*A*).

Application of the linear correction *jCt*1 to the angular quantity *A* is as follows: It will be noted that changes in *Ct*



TARGET COURSE AND BEARING

A

TARGET VECTOR COMPONENTS

D

TARGET BEARING RATE COMPONENTS

C

HORIZONTAL RANGE RATE COMPONENTS

B

Figure 4-4.—Vector diagrams.

are accompanied by corresponding changes in $A$. From figure 4–4D it is seen that the increment of change of target course ($jCt$) can be expressed by the equation:

$$jCt = \tan^{-1}\left[\frac{jCt1}{jSh}\right].$$

For such small angles as are involved, the tangent can be assumed equal to the corresponding arc expressed in radians. Thus the expression for $jCt$ can be taken as:

$$jCt \text{ (in degrees)} = \frac{jCt1}{2\ Sh} \times 360, \text{ or } jCt = \frac{jCt1}{K'Sh}.$$

This expression indicates that for a given value of $jCt1$, $jCt$ will vary with $Sh$. However, it has been determined that sufficiently accurate results can be obtained by assuming a constant speed, the expression thus becoming:

$$jCt = \frac{jCt1}{K}.$$

This simplifies the mechanism, enabling the linear correction $jCt1$ to be converted to an angular correction to $Ct$ by means of gear ratios. This correction, $jCt$, is applied to $Ct$ at the $Ct$ follow-up, and it is ultimately applied to target angle, $A$, in a differential.

## SENSITIVITY CONTROL

Considered functionally, the sensitivity control of Computer Mk 1A is comprised of two separate and independent networks, i. e., the sensitivity control of the range rate control network, and the sensitivity control of the elevation and bearing rate control networks. Before describing either of the sensitivity control networks, a more general description of sensitivity control must be given.

The time constant and sensitivity of the instrument determine the amount of target motion rate correction resulting from a given instantaneous rate error measurement. Provision was made in Computer Mk 1 for varying the sensitivity of the range rate control network. This made it possible for the operator to increase the sensitivity temporarily to hasten the reduction of large errors; and then to return to a more stable value as the solution was approached. No change was made in the sensitivity control of the range rate control network when altering a Computer Mk 1 to a Computer Mk 1A except for recalibrating the range rate ratio knob to read directly as range time constant.

Computer Mk 1 did not incorporate any means for sensitivity control of the elevation and bearing rate networks. The ratio of the difference between observed and generated changes in elevation or bearing to the resulting linear correction was fixed. Thus the operator had no control over the sensitivity of these networks, and the time constant (*Tc*) varied at a fixed rate with range. (See fig. 4–5.) The rate of change of the time constant of Computer Mk 1 with respect to range can be expressed by the formula:

$$Tc=\frac{R}{1430}\ \text{(Approx.)}$$

where *Tc* is time constant in seconds, and *R* is present range in yards.

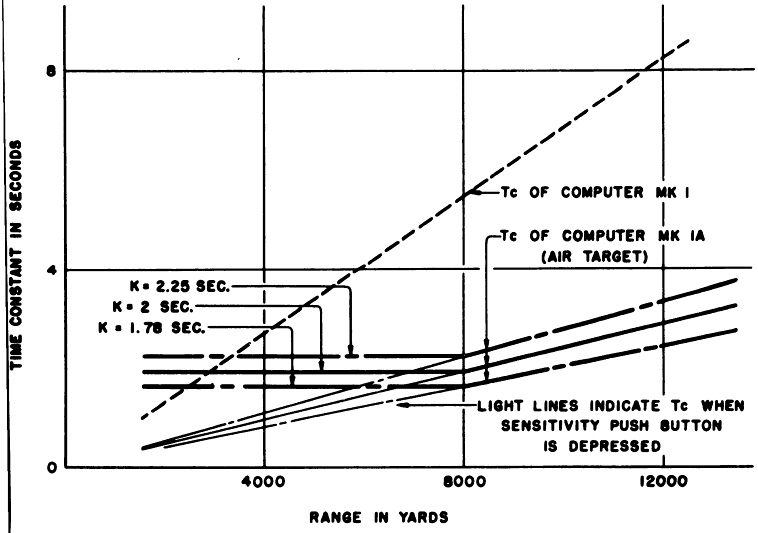


**Figure 4–5.—Computer time constant versus range (air target).**

In Computer Mk 1A, operation of the elevation and bearing rate control networks is improved by:

1. Increasing sensitivity of these networks.
2. Provision for keeping the time constant uniform between the ranges of 500 yards and 8,000 yards.
3. Provision of means for the operator to vary the sensitivity temporarily (by temporarily changing the time constant). These features are incorporated in the elevation and bearing sensitivity control network, a detailed description of which follows.

The mechanisms involved in the sensitivity control network are the bearing, elevation, and range correction integrators; the time constant change gears; the rate control range receiver; the time constant control transmitter; the air-surface switch; the sensitivity push button; and the time delay relay. (See fig. 4–3.)

CORRECTION INTEGRATORS. The integrators are of the disk type, the integrator for range having a four-inch disk and the integrators for elevation and bearing three-inch disks. The integrator for range is designated as the range correction ratio changer.

TIME CONSTANT CHANGE GEARS. Two sets of time constant change gears are provided for the elevation rate mechanism. Two identical sets are provided for the bearing rate mechanism also. The gears are engraved with time constant values and letters. The letters indicate the shafts on which they are installed. The gears engraved "*A*, $Tc=2.00$" and "*B*, $Tc=2.00$" form one set. When these gears are installed on shafts *A* and *B*, the basic time constant of the network in which they are installed is 2.00 seconds. The basic time constant is that value of $Tc$ that is kept uniform between the ranges of 500 yards and 8,000 yards. It is also one of the factors determining the slope of the line representing the changing values of $Tc$ beyond 8,000 yards range. (See fig. 4–5.) The basic time constant will be described further in the ensuing functional description, but it should be noted here that the basic time constant is inherent in the gearing of the system; the change gears merely provide a means of altering it.

The other change gears are engraved as follows:
Gear number 616728 (smaller gear)

$A$, $Tc$ 2.25
$B$, $Tc$ 1.78.

Gear number 616729 (larger gear)

$B$, $Tc$ 2.25
$A$, $Tc$ 1.78.

When the smaller gear is installed on shaft $A$ and the larger gear on shaft $B$, the basic time constant is 2.25 seconds. When they are installed in the reverse manner, the basic time constant is 1.78 seconds.

It will be shown in the functional description that the time constant of the bearing rate control network varies with elevation as well as with range. Thus, in the bearing network the value indicated by the installed gears is the basic time constant for this network only when the secant of target elevation ($E$) is 1.1, which occurs when $E$ is approximately 25 degrees.

RATE CONTROL RANGE RECEIVER. The rate control range receiver is a single-speed receiver. Range is received by a 1$F$ synchro receiver. The synchro receiver controls the position of the servo motor through a contact arrangement similar to that of the fine contact assembly of the range receiver located under the fine and coarse present-range dials.

TIME CONSTANT CONTROL TRANSMITTER. This is a 1$G$ synchro transmitter. It transmits a predetermined value of rate control range. The transmitted range is indicated by a drum dial graduated from 0 to 10, representing zero to 10,000 yards. The transmitter can be set at predetermined values by turning a worm and gear type of adjustment on the transmitter shaft. Access to the adjustment is had by removing a pipe plug located below and to the left of the range time constant knob. It is called the time constant control transmitter because signals from it to the rate control range receiver affect the value of the time constant in surface fire.

AIR-SURFACE SWITCH. This is a double-pole, double-throw switch.

SENSITIVITY PUSH BUTTON. The sensitivity push button actuates a switch in which the contacts are normally closed. Pushing the button opens the contacts.

TIME DELAY RELAY. The time delay relay is a double-pole, double-throw, solenoid-operated switch. The time delay characteristic is obtained by requiring the switch-actuating rod to compress and expel air from a chamber in the timing head before tripping the toggle switch. When the solenoid is energized, motion of the solenoid core compresses a spring. The spring, acting on a diaphragm, compresses the air in the timing head. The time delay is controlled by means of a regulating screw that governs the rate at which the air can be expelled through a needle valve. The switch operates at a predetermined point in the stroke of the diaphragm. When the coil is de-energized, the spring quickly returns the solenoid plunger and actuates the switch in the opposite direction.

## Sensitivity Control of Range Rate Control Network

Sensitivity of the range rate control network is controlled through the range correction integrator. This unit functions in the same manner as it did in the Computer Mk 1 (see OP 1064). The only difference is in the knob used for positioning the carriage of the range correction integrator. This knob is now designated the range time constant knob, and the graduations used in setting it have been changed. In the Computer Mk 1A it is graduated in terms of the time constant, from 0 to 16 seconds. The number at which the knob is set indicates the time (in seconds) required for a range rate error to be reduced to approximately 37% of its initial value.

## Sensitivity Control of *E* and *B* Rate Control Networks

Figure 4–3 shows schematically the network for controlling the sensitivity of the elevation and bearing rate control networks of Computer Mk 1A. In the figure, the dotted lines indicate electrical circuits. Inputs to the sensitivity control network are angular elevation rate error ($j\dot{E}$), angular bearing rate error ($jBr$), and rate control range ($R''$). The latter quantity, $R''$, is the value of range represented by the actual position of the mechanism. It may or may not equal observed range, depending on circumstances of the fire-control problem or on the conditions of operation. Changes in the input of $R''$ cause simultaneous changes in the sensitivity of the elevation and bearing rate control networks. The operation of the sensitivity control network in determining the amount of linear rate correction that is applied to reduce a given rate error is the same for both elevation and bearing. Therefore a description of the operation as applied to one network will serve for both.

Determination of elevation rate control sensitivity. It was indicated previously that the elevation correction integrator is used to multiply the angular elevation rate error ($jE$) by present range to obtain the equivalent linear elevation rate correction. Accordingly, if rate control range ($R''$) equals present range ($R$), then either of the equations, $(R)\ (jE)=jEc$ or $(R'')\ (jE)=jEc$, expresses the value of the linear correction. But it also has been indicated that, for purposes of stability, the value of the linear rate correction actually applied in the instrument should be less than that expressed by the above formulas. This reduction is effected in two ways, as follows:

1. By introducing a fixed ratio having a value less than unity in the $jE$ input.
2. By varying the value of $R''$.

The ratio in the $jE$ input is incorporated in the gearing. It is thus fixed and not controllable by the operator. Designating this ratio as $Q$, the input to the elevation correction integrator disk becomes $[(Q)\ (jE)]$. Thus, with $R''$ equal to $R$ the formula for $jEc$ becomes:

$$jEc=R\ [(Q)\ (jE)].$$

However, if $R''$ is varied with respect to $R$, the output of the integrator varies in the same proportion. Thus, the complete expression for $jEc$ is:

$$jEc=\frac{R''}{R}(R)\ [(Q)\ (jE)]$$

this can be rewritten to read:

$$jEc=\left[(Q)\frac{R''}{R}\right][(R)\ \ (jE)].$$

The expression $(Q)\frac{R''}{R}$ indicates the actual sensitivity of the complete network. In discussing the operation of the network, it is more convenient to refer to the time constant $(Tc)$, which is the reciprocal of the sensitivity factor, or $\left[\left(\frac{1}{Q}\right)\left(\frac{R}{R''}\right)\right]$. Letting $Ke=\frac{1}{Q}$, this becomes:

$$Tc=(Ke)\frac{\mathrm{R}}{R''}.$$

The *e* indicates that the constant is applied to the elevation network.

The constant, *Ke*, is the basic time constant of the network. As long as the input of *R''* equals *R* (i. e., the ratio $\frac{R}{R''}=1$), *Tc* equals *Ke*, which, expressed in seconds, represents the time required for the network to reduce the error to 37% of the initial value. The constant, *Ke*, is introduced throughout the gearing of the instrument; the change gears previously referred to merely provide a selection of the values 1.78, 2.00, or 2.25 seconds.

The range input to the sensitivity control network is limited to a maximum value of 8,000 yards. Referring to figure 4–3, it is seen that the input of *R''* is derived from range sent to the rate control range receiver from either the rangefinder or the time constant control transmitter. When *R''* is received from the rangefinder and is not more than 8,000 yards, *R''* equals *R*, and the time constant of the network is *Ke*. For ranges beyond 8,000 yards but below 22,500 yards, the time constant increases uniformly because the ratio $\left(\frac{R}{R''}\right)$ no longer equals unity, *R''* being held at 8,000 yards while *R* continues to increase. As an example, with *R* at 16,000 yards, and 2-second change gears installed:

$$Tc=Ke\left(\frac{R}{R''}\right)=2\left(\frac{16{,}000}{8{,}000}\right)=4 \text{ seconds.}$$

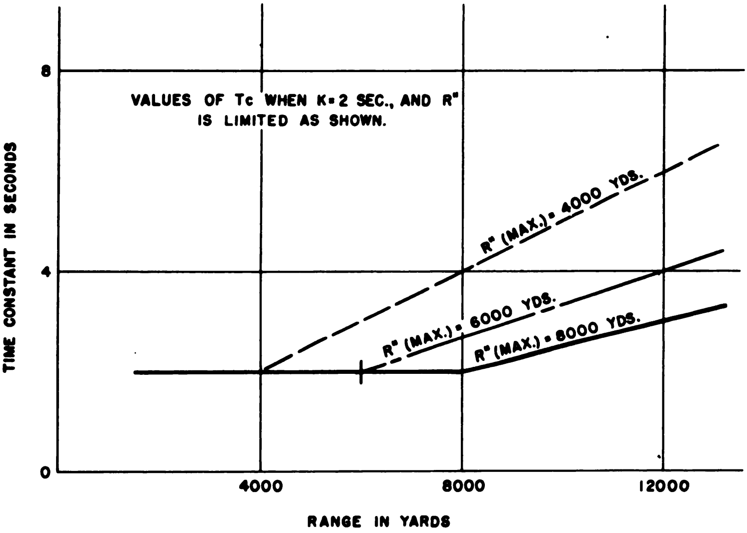


Figure 4–6.—Effect of decreasing upper limit of $R''$.

The values of $Tc$ for all values of range up to about 14,000 yards are shown graphically in figure 4–5. The increasing values of $Tc$ beyond 8,000 yards provide greater stability but larger errors at long ranges. However, the increased stability improves the pattern of the projectiles at these ranges. Means are provided for changing the upper limit of the range stop from 8,000 yards to 3,000, 4,000, 5,000, 6,000, or 7,000. The effect of decreasing the upper limit of $R''$ is indicated in figure 4–6. It can be seen that below the limit $Tc$ remains constant, while for values of range beyond the limit the time constant increases as the value of the limit decreases.

Now consider the determination of bearing rate control sensitivity. As previously stated, bearing rate control sensitivity is similar to that for elevation. It differs in but one respect; the time constant of the bearing network varies with the value of elevation ($E$), as well as with range, because the horizontal projection of range ($R$ cos $E$) determines the linear bearing rate correction required. Accordingly, the relationship between linear and angular bearing rates is:

$$jBc = (R \cos E)\ (jBr).$$

Inserting the sensitivity factor:

$$jBc = Q \left[\frac{R'' \cos E''}{R \cos E}\right]\ (R \cos E)\ (jBr).$$

Here, $E''$ is the value of elevation actually entering the sensitivity control mechanism. A constant value of $E''$ is selected as satisfactory for the purpose of computing rate corrections, as explained below. Since the cosine of a constant angle is itself a constant, cos $E''$ can be replaced in the equation by $K1$. Thus, the expression for $jBc$ becomes:

$$jBc = (Q) \left[\frac{(R'')\ (K1)}{R \cos E}\right] (R \cos E)\ (jBr).$$

Letting $Kb = \frac{1}{Q}$, the expression for the time constant of the bearing rate control network becomes:

$$Tc = Kb \left[\frac{R\ (\cos\ E)}{(R''K1)}\right].$$

The $b$ of $Kb$ merely indicates that the constant applies to the bearing network.

The formula for $Tc$ in bearing can be rewritten in several ways:

$$Tc = Kb \left[\left(\frac{R}{R''}\right) \cos E\right] \frac{1}{K1}, \text{ or}$$

$$Tc = Kb \left[\left(\frac{R}{R''}\right) \cos E\right] \sec E'',$$

sec $E''$ being $\frac{1}{\cos E''}$ or $\frac{1}{K1}$.

From the above, the desirability of selecting a value for $K1$ that approximates the secant of $E$ over a wide range of variation can readily be seen. The constant 1.1 is applied in the instrument gearing of the Mk 1A as $K1$. The secant of 0° being 1.0, and the secants of 25° and 35° being approximately 1.1 and 1.2, respectively, the selection of 1.1 as the value of $K1$ represents a reasonable mean value for usual fire control problems. Thus, as long as target elevation does not exceed 35°, the values of $Tc$ given in figure 4–5 can be applied to the bearing network without serious error.

## TO SUMMARIZE

It has been shown that the only difference between the elevation and bearing time constant in Computer Mk 1A is the factor $\frac{K1}{\cos E}$. For simplicity, this difference will be ignored in the following description; the elevation and bearing time constants will be considered equal.

The bearing and elevation time constant of Computer Mk 1 can be expressed by the formula, $Tc=\frac{R}{1430}$, in which $R$ equals range in yards. (See fig. 4–5.) No provision is made for operational control of this time constant.

As indicated in figure 4–5, the time constant of Computer Mk 1A is made shorter than that for Computer Mk 1 at long ranges. However, these values of $Tc$ are still large enough to provide sufficient stability to insure small dispersion patterns. The constant value of $Tc$ shown for short ranges is a compromise between stability and fast solution time. In Computer Mk 1A, provision is made for altering the value of $Tc$ at the will of the operator. Thus faster solution times can be obtained than those provided by the uniform value of $Tc$, as indicated by the light lines in the figure. The operator controls the operation of the sensitivity control network by means of the air-surface switch and the sensitivity push button.

## AIR TARGETS

For operation against air targets, the air-surface switch is positioned at AIR. The range input from the rangefinding equipment then actuates the rate control range receiver, and the value of $R''$ applied in the network is equal to $R$, up to the limit of 8,000 yards. With the 2-second $Tc$ gears installed, the time constant $Tc=K\frac{R}{R''}$ becomes:

1. $Tc=2$ for ranges to 8,000 yards.

2. $Tc=2\times\frac{R}{8{,}000}=\frac{R}{4{,}000}$ for ranges beyond 8,000 yards.

See figure 4–5.

If conditions of the problem indicate the desirability of increased sensitivity, it can be obtained, when range is 8,000 yards or less, by depressing the sensitivity push button.

The rate control range receiver (fig. 4–3) is of the type wherein both coils of the servo motor stator are energized directly by the power supply when the input and output are in synchronism. Depressing the sensitivity push button opens the time delay relay solenoid circuit. The relay then operates as previously described under the heading "sensitivity control mechanism," and shifts the single letter side of the power supply from the center contact of the receiver follow-up to the left lead of the rate control servo motor, at the same time disconnecting the left follow-up contact from the left side of the servo. With the left side of the servo connected directly to the power supply, the motor then drives range to the upper limit. After the sensitivity push button is released, the time delay relay maintains the direct connec-

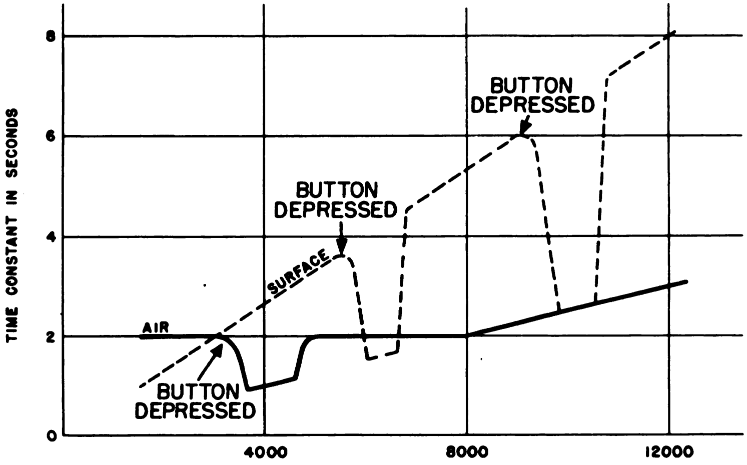


**Figure 4–7.—Effect of depressing sensitivity push button on computer time constant.**

tion to the left lead of the servo for the duration of the delay period, which is usually set at approximately two seconds.

From the above it is seen that depressing the sensitivity push button causes the input, $R''$, to remain at 8,000 yards for a brief period. During this time the ratio $\frac{R}{R''}$, in the formula, $Tc = (2)\,\frac{R}{R''}$, will not equal unity, and the time constant for any range under 8,000 yards will be shortened as indicated by the light lines in figure 4–5.

Figure 4–7 shows the effect of depressing the sensitivity push button on a typical problem, both surface and air, in which range is changing.

## SURFACE FIRE

It has already been indicated the Computer Mk 1A can be operated automatically against surface targets (normal control in Computer Mk 1A being the same as automatic control in Computer Mk 1). For such operation, the air-surface switch is set at SURFACE. When so positioned it disconnects the rate control range receiver from the rangefinder, and connects it instead to the time constant control transmitter. The input to the rate control range receiver from the time constant control transmitter is equivalent to a fixed value of range. Assuming the control transmitter to be set to transmit a value equivalent to 3,000 yards, the formula expressing the time constant of Computer Mk 1A (2-second time constant gears being installed) for surface fire is:

$$Tc = (2)\frac{R}{3{,}000} \text{ or } Tc = \frac{R}{1{,}500}.$$

This gives values of $Tc$ with respect to range approximately equal to those shown in figure 4–5 for Computer Mk 1. The effect of other settings on the time constant is indicated in figure 4–8. Increased sensitivity can be obtained by depressing the sensitivity push button. This has the effect of setting $R''$ at a fixed value equal to the upper limit of the stop. The $R''$ input is held at this higher value for approximately two seconds after the sensitivity push button is re-

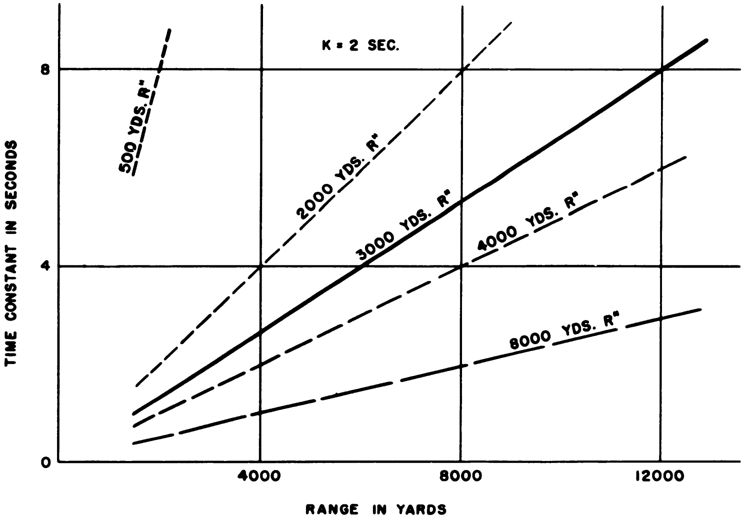


Figure 4–8.—Effect of time control constant transmitter setting on *Tc*.

leased. The resulting effect on a typical problem is indicated in figure 4–7. Two conditions are shown, one for a range greater than 8,000 yards, one for a shorter range.

## LOCAL CONTROL

In local control the rate control computing mechanism is inoperative. In this form of operation Computer Mk 1A performs in the same manner as described in OP 1064 for Computer Mk 1.

## NORMAL (AUTOMATIC) CONTROL

Normal control of Computer Mk 1A corresponds to automatic control of Computer Mk 1. Therefore, the description of automatic operation contained in OP 1064 is applicable for Computer Mk 1A when modified by the information given in this chapter. However, it should be noted that the illustrations in OP 1064 showing the rate control computing mechanisms do not show the parts entirely as they are in Computer Mk 1A. To rectify this condition, reference should be made to figures 4–2, 4–3, 4–9 and 4–10 of this book.

Differences in the Mk 1 and Mk 1A rate control mechanisms

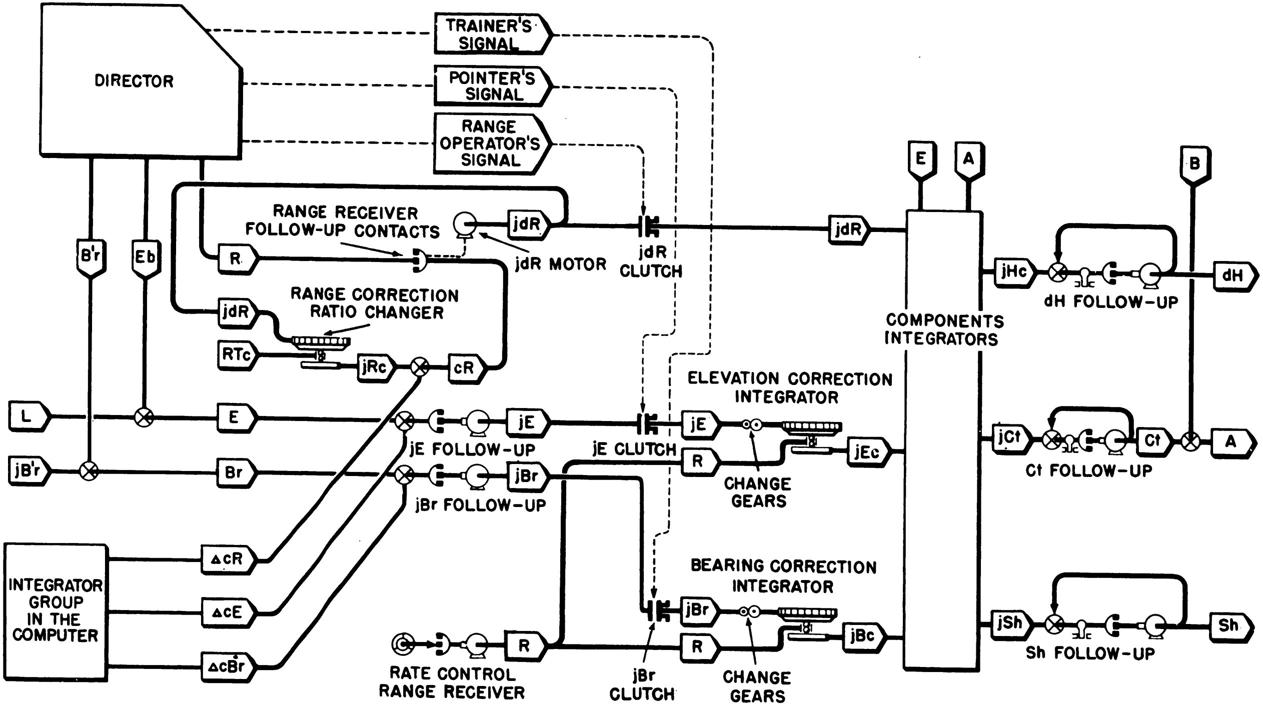


Figure 4-9.—Flow schematic (normal control).

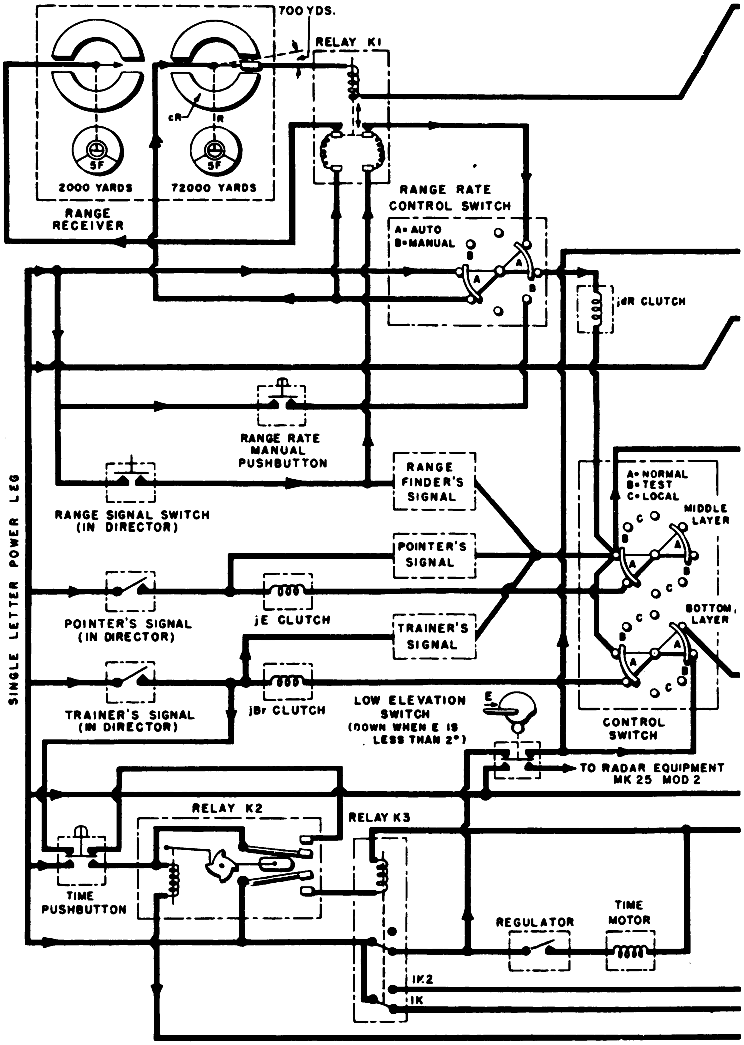


**Figure 4—10.—Automatic operating controls.**

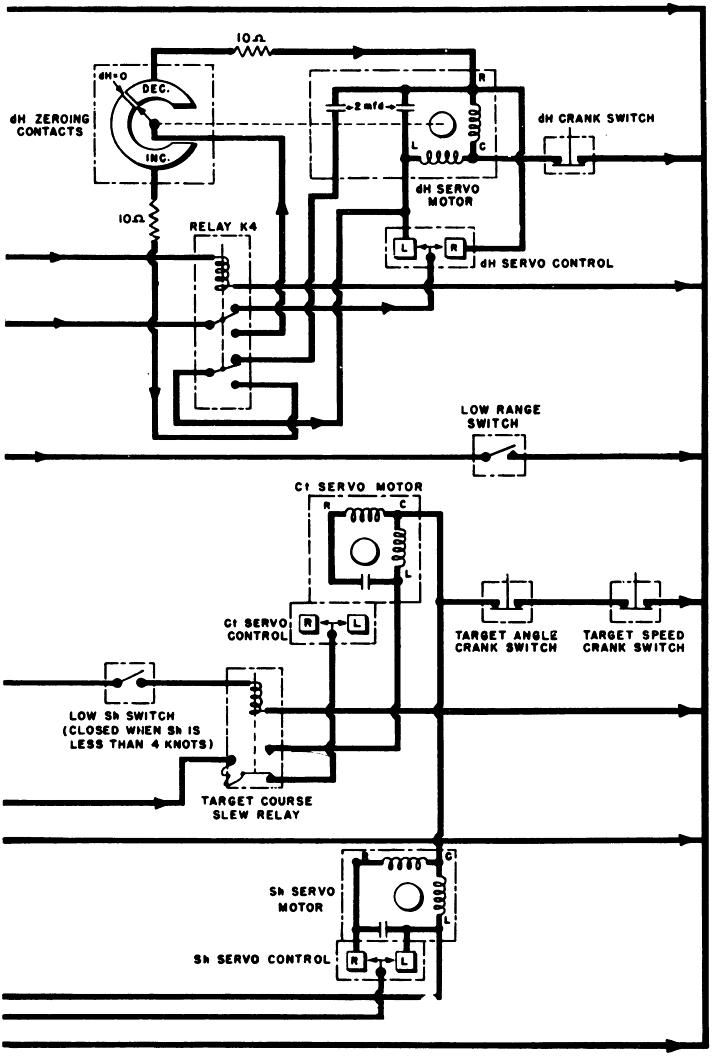


Figure 4–10.—Automatic operating controls (continued).

have already been described in this chapter. Figure 4–9 shows the Mk 1A rate control mechanism in normal control. The control circuits governing the operation of the rate control mechanism of Computer Mk 1A differ from those of Computer Mk 1. The Mk 1A circuits are described below, and are shown schematically in figure 4–10.

## AUTOMATIC TRACKING CONTROLS

For full automatic operation of Computer Mk 1A the control switch is set at NORMAL and the range rate control switch is set at either AUTO or MANUAL. The basic features of operation in this condition are fully described above. However, normal operation is affected by operation of the automatic tracking controls which are described in detail below. Reference should be made to figures 4–9 and 4–10 throughout the following description.

The automatic tracking controls of Computer Mk 1A operate to:

1. Automatically start the time motor when the director first indicates that it is "on target."
2. Automatically keep the generated range and the observed range dials in agreement even though the range-finding equipment does not indicate that it is "on target."
3. Prevent the $jdR$ clutch from being closed unless generated range is within 700 yards of agreement with observed range.
4. Automatically slew target angle until rate control increases target speed ($Sh$) above four knots, and target angle ($A$) is less than 90° in error.
5. Automatically set target speed ($Sh$) and rate of climb ($dH$) at zero when the time motor is not running.
6. Transmit an electrical signal to the director when target elevation ($E$) is less than two degrees.

The purpose of these controls is to simplify and improve the operation of the gun fire-control system.

In Computer Mk 1, initial estimates of target motion ($A$, $Sh$, and $dH$) must be set in the computer to establish initial target motion rates. But when the time motor is started, these rates are transmitted to the director where they are superimposed on whatever signal is positioning the director, and thus tend to drive the director off the target. In addition, if an incorrect estimate of *A* has been applied (or if no estimate of *A* is available), so that the applied value of *A* differs greatly from the actual value, considerable time is required for the computer to arrive at a correct rate control solution. A further disadvantage of this system is that, during the interval between the time the trainer indicates he is "on target" and the time the computer operator starts the time motor, the computer rate system is upset. These disadvantages are reduced in Computer Mk 1A by the control mechanisms which operate as indicated in items 1, 4, and 5 above. In Computer Mk 1A, the computer rates are at zero when the time motor is started, and the director is not driven off the target. With the starting of the time motor, *A* will be slewed to the proper quadrant, if necessary, and the correct rates quickly established in the computer. The necessity for the introduction of target motion rates by the operator is eliminated.

Another purpose of the added controls is to relieve the operator of the necessity of keeping the generated and observed range dials matched during the period of target acquisition. In Computer Mk 1A, the electrical circuits have been so arranged that the *jdR* motor keeps these dials synchronized whenever the range rate control switch is at AUTO. If observed range changes too rapidly for the *jdR* motor to follow, the control mechanism opens the *jdR* clutch when the difference between observed and generated range becomes 700 yards (item 3 above). This prevents erroneous range rates from being set into the computer.

There are several other functions of the automatic control mechanisms of Computer Mk 1A. These are explained in the following descriptions which give the details of each control separately.

## The Control Switch

The description of the control switch in OP 1064 is applicable to Computer Mk 1A when the following substitutions in the wording are made: NORMAL for AUTO, and TEST for SEMI-AUTO.

### The Pointer's and the Trainer's Signal Keys

These switches function as described in OP 1064. In Computer Mk 1A the trainer's signal key has the additional function of starting the time motor upon a shift to normal control. This is explained in detail in this chapter under the heading "Time Motor Control System."

### The Range Rate Control Switch

The description of this switch given in OP 1064 is applicable to Computer Mk 1A when it is borne in mind that there is no semi-auto rate control in Computer Mk 1A. Another important difference is that, in Computer Mk 1A, turning the range rate control switch to AUTO energizes the range receiver. This operation is entirely independent of the completion of circuits in the director. Thus, in automatic control the range dials are kept in agreement at all times.

### The Range Operator's Signal Button

The range operator's signal button in the director controls the operation of the *jdR* clutch and rangefinder signal, as described in OP 1064. However, relay *K*1 of the automatic

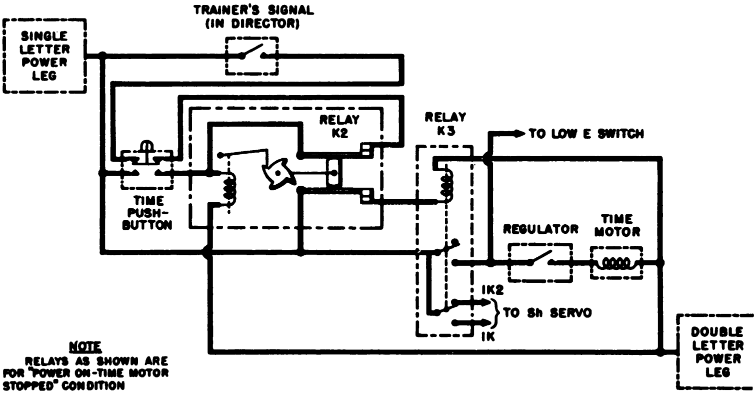


Figure 4–11.—Time motor control system (power on—time motor stopped).

tracking controls modifies this operation, as described under the heading "Control of Range Input" in this chapter. The remainder of this section concerns the Mk 1A Computer.

Figure 4–11 shows the system for starting and stopping the time motor. As shown in the figure, the system is in the "Power On—Time Motor Stopped" condition. Thus, the ratchet-operated contacts of relay $K2$ are closed, and the solenoid of relay $K3$ is energized. When the solenoid of relay $K3$ is energized, the switch of this relay opens the time motor line thereby stopping the time motor.

Relay $K2$ is so constructed that successively energizing its solenoid causes the ratchet mechanism alternately to open and close the contacts in the relay; i. e., one cycle of operation of the solenoid will cause the contacts to open, the next will cause them to close. With the computer power ON, depressing the time motor push button energizes this solenoid. Likewise, closing the trainer's signal key will energize the solenoid when the system is in the condition shown in figure 4–11 ("Power On—Time Motor Stopped" condition).

With the system in the condition shown in the figure, depressing the trainer's signal key starts the time motor in the following manner. The initial effect is to energize the solenoid of relay $K2$. This actuates the ratchet mechanism of the relay and opens the relay contacts. Since power for the solenoid must come through one pair of the contacts, the solenoid is de-energized, setting the relay for the next cycle of operation. As soon as the relay contacts are opened, the solenoid of relay $K3$ is de-energized also. This causes relay $K3$ to close the time motor line to start the time motor.

To stop the time motor, the time motor push button on the computer is depressed. Reference to either figure 4–10 or figure 4–11 shows that this energizes the solenoid of relay $K2$, causing the relay to cycle and restore the condition illustrated in figure 4–11, wherein the contacts are closed, relay $K3$ is energized, and the time motor stopped.

The time motor cannot be stopped by means of the trainer's signal key because, in starting the time motor, the contacts of relay $K2$ are opened, thereby disconnecting this switch from the relay solenoid.

The time motor control system also governs the operation of the $Sh$ and the $dH$ servo motors in the manner described under the two headings, Zeroing $Sh$ and Zeroing $dH$.

### Zeroing *Sh*

Referring to figure 4–10, it is seen that power for operating the $Sh$ servo motor is supplied through either line $1K$ or line $1K2$.

When the solenoid of relay $K3$ is energized, the relay is actuated to connect line $1K2$ to the power supply, while at the same time disconnecting line $1K$. Line $1K2$ is connected to the left leg of the $Sh$ servo motor. Thus, when this line is energized, the $Sh$ servo motor drives in the decreasing direction; in other words, when the time motor is stopped, $Sh$ is set at zero also.

In starting the time motor the solenoid of relay $K3$ is de-energized. The relay then disconnects line $1K2$ from the power supply, connecting line $1K$ instead. Thus, when the time motor is started, the $Sh$ servo motor is again governed by the $Sh$ servo control.

### Zeroing *dH*

As long as the solenoid of relay $K4$ is energized, the switch of the relay will be positioned as shown in figure 4–10, and operation of the $dH$ servo motor will be governed by the $dH$ servo control. It is seen in figure 4–10 that the power supply to the solenoid is taken from the time motor line and passes through the low elevation switch. Thus, if the time motor control operates to stop the time motor or if the line is opened by the low elevation switch, the solenoid of relay $K4$ is de-energized and connections to the $dH$ servo motor are as indicated in figure 4–12. The $dH$ motor is then controlled by the $dH$ zeroing contacts, which cause it to be driven to and held at the zero $dH$ position.

These contacts consist of two fixed segments and a rotating contact that is driven by the servo motor. Each segment is connected to one lead of the $dH$ servo motor as indicated in figure 4–12. Power is applied through the rotating con-

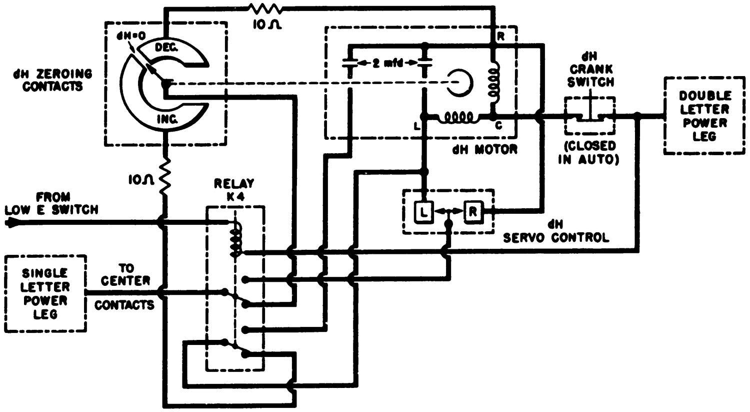


Figure 4–12.—The *dH* zeroing system.

tact. The connections are such that, when the contacts are in control, the motor drives until it reaches the zero position, at which time the rotating contact is between the two segments. Since connection is then equal to both motor coils, the motor stops running.

Referring to figures 4–10 and 4–12 it will be noted that 2-mfd capacitors are connected in the motor circuit when the relay is set for operation of the *dH* servo control, while when the zeroing contacts are operative, one of the capacitors is cut out of the circuit and a 10-ohm resistor is connected in series with each coil of the motor. This arrangement prevents excessive over-travel of the zero points when zeroing *dH*.

## THE LOW *E* SWITCH

The low elevation switch is a cam-operated double-throw micro switch. The cam is mounted on the elevation transmitter shaft, and the switch is electrically connected as indicated in figure 4–10. When *E* is greater than 2° the switch is positioned as shown.

When *E* becomes less than 2°, the cam moves the switch to the opposite position, thereby de-energizing the solenoids of the target course slew relay and relay *K*4, and causing a 115 volt, 60-cycle signal to be transmitted to a signal light in the director. The effect of de-energizing the solenoid of relay *K*4 has already been described. The effect of de-energizing the target course slew relay solenoid is described below.

### The Target Course Slew System

The principal purpose of this system is to establish the instrument setting of target angle (*A*) in the proper quadrant as soon as the time motor is started so that the computer will rate control properly. The component parts of the system are the low *Sh* switch and the target course slew relay.

The low *Sh* switch is a micro switch actuated by the *Sh* limit stop. When *Sh* is less than four knots the switch is closed.

Figure 4–10 indicates the manner in which the low *Sh* switch, the target course slew relay, and the *Ct* servo motor are electrically connected. It is seen from the figure that the single letter power input to the *Ct* servo motor passes through the relay. With the low *Sh* switch open, the relay solenoid is de-energized and connections at the relay are as indicated in the figure. This causes operation of the *Ct* servo motor to be under control of the *Ct* follow-up control. When *Sh* is less than four knots, the low *Sh* switch is closed, energizing the target course slew relay solenoid. This causes the relay to disconnect the power supply from the *Ct* servo control and to connect the left lead of the *Ct* servo motor directly to the power supply. The motor then drives until the relay position is reversed, as described below.

Now let us consider the operation of target course slew system. It has been shown in the description of the time motor control system that, when the time motor is stopped, the value of *Sh* applied in the instrument is automatically brought to zero. A study of the rate control mechanism (particularly the component integrators) will show that, when the input of target angle (*A*) is more than 90° in error, the mechanism reduces the computed value of *Sh*. Thus, if the input of *A* is more than 90° in error when the time motor is started, the rate control mechanism operates to hold *Sh* at zero until *A* is positioned less than 90° in error. Under these conditions the target course slew system operates as described in the preceding paragraph, slewing target course (*Ct*), and bringing it rapidly to the proper quadrant. As *A* enters this position the rate control mechanism commences moving *Sh* in the increasing direction. When *Sh* exceeds four knots the low *Sh* switch is opened, the target course slew relay solenoid is de-energized, and operation of the *Ct* servo motor is again governed by the *Ct* follow-up control. If, for any reason, target angle (*A*) is positioned more than 90° in error after rate control has commenced, operation to restore it to the proper quadrant is similar to that described above.

It should be noted here that it is still possible to slew the *Ct* motor by means of the increase and decrease buttons on the target course indicator (see OP 1064) if *Sh* is more than four knots. When operating against surface targets, this operation can be performed when *Sh* is below four knots. It can be seen from figure 4–10 that, when the low elevation switch is positioned for an elevation of less than 2°, the solenoid of the target course slew relay will not be energized, even though the low *Sh* switch is closed. This makes normal operation against surface targets possible.

## CONTROL OF RANGE INPUT

It has already been stated that when the range rate control switch is at AUTO the range receiver is energized. Thus, range is set into Computer Mk 1A even though the rangekeeper operator does not indicate he is on target. To make it unnecessary for a computer operator to match the range dials during the target acquisition period, and to prevent erroneous range rates from being generated if the range signal switch is closed before *R* and *cR* are in agreement, relay *K*1 is provided (see fig. 4–10). It can be seen in the figure that the solenoid of the relay is energized from the island contact of the coarse range receiver motor contact group. When *cR* in the computer is within 700 yards of agreement with the input of range, the solenoid is energized, and the relay switch is positioned as shown. When so positioned, the switch closes two circuits. One connects the fine range receiver follow-up contact to the power supply; the other connects the *jdR* clutch and range signal switch. Thus, *R* and *cR* can be brought into exact agreement, and the *jdR* clutch can be closed whenever the range signal button is pressed. When the difference between *cR* and *R* exceeds 700 yards, the center coarse contact is moved sufficiently from the synchronized position (in which it is shown in fig. 4–10) to de-energize the solenoid of relay *K*1 thus opening the relay. It is then impossible to close the *jdR* clutch and rate control while the range receiver is out of synchronism. The rangefinder signal is, however, still operable. Also, the range receiver is then in coarse control only.

## LOW RANGE SWITCH

If rate inputs are set into the rate control computing mechanism when range is less than 1500 yards, erroneous values of target angle and target speed are generated because the 1/*cR* cam has a constant radius below 1500 yards. In Computer Mk 1A a microswitch is installed to prevent these inputs when *R* is less than 1500 yards. This switch is connected electrically to the rate control clutches, as indicated in figure 4–10, and is actuated by the carriage of the 1/*cR* cam. When *cR* passes below 1500 yards the switch is opened, preventing the energization of the clutches. Thus, inputs of *jE*, *jBr*, and *jdR* are prevented when range is less than 1500 yards.

## QUIZ

1. **How does the target vector rate control system improve the performance of the computer?**
2. **The measured elevation rate error (*jE*) and the measured bearing rate error (*jBr*), being angular quantities, are converted into linear quantities. How is this accomplished in the Mk 1A computer?**

3. In the Mk 1A, *jBc* and *jdRh* are resolved into horizontal components taken with respect to what plane?
4. Which input to the target angle component integrators has replaced target bearing (*B*)?
5. What change was made in the sensitivity control of the range rate control network when the Mk 1A computer was developed from the Mk 1?
6. What is indicated by the number at which the range time constant knob is set?
7. How does the computer operator control the sensitivity control network?
8. Normal control in the Computer Mk 1A is the same as what control in the Mk 1 Computer?
9. When do the automatic tracking controls operate to start the time motor?
10. What is the difference between observed and generated range when the *jdR* clutch opens?
11. What is the purpose of additional automatic tracking controls in the Mk 1A?
12. What is the range input limit to the sensitivity control network?

# CHAPTER 5

## THE AA FIRE-CONTROL SYSTEM—THE DIRECTOR

In the preceding chapters you studied ballistics, own ship and target motion, gun and fuze orders, and rate control—all components of the antiaircraft problem. At the same time you learned about the mechanisms that perform the individual computations. Now you are ready to tie these computations to the actual equipment—the Mk 37 director system.

The Mk 37 system is complex. And yet, when the system is analyzed, we find the same electrical and mechanical basic mechanisms common to all fire-control equipment. For this reason we shall consider the flow of information between the units, and then study the units separately. Operation of the system will be considered last.

The Mk 37 director, Mk 1A computer, and Mk 6 stable element are the main components of the system. They are tied together, and to the fire-control radar, bridge, combat information center, star-shell computer, ship gyro compass, pitometer log, and target designation system, by a variety of telephone, electrical, and mechanical connections.

The director furnishes target information and is the control center of the system. The stable element supplies the corrections for the roll and pitch of the ship. The computer—as the mechanical brain of the system—receives this information, computes, and transmits the gun orders required to keep the guns pointed at the predicted position of the target. See figure 5–1.

### THE FLOW OF INFORMATION

The Mk 37 director system, in its various modifications, is designed for the primary control of 5″/38's, 5″/54's, and

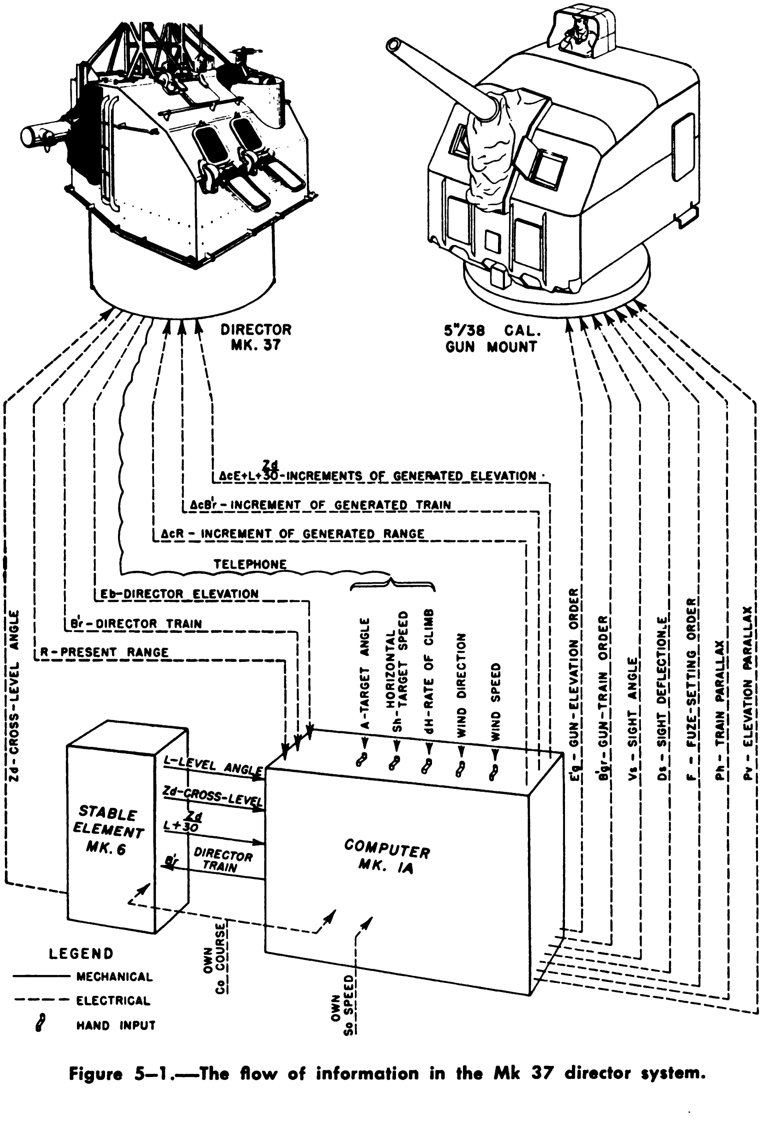


Figure 5–1.—The flow of information in the Mk 37 director system.

6″/47's against either aerial or surface targets. And, at short ranges, the system can also be used for the secondary control of 3″/50 and 40-mm. guns. The system also controls the illumination of a surface target with searchlights or star-shells.

The principal connection between the director, computer, stable element, and guns is shown in figure 5–1. All the electrical connections are made through the fire-control switchboard.

The director measures director elevation $Eb$, director train $B'r$, and present range $R$, and transmits these values electrically to the computer. The control officer estimates target angle $A$, target horizontal speed $Sh$, and rate of climb $dH$, and sends their values by telephone to the computer operators. Spot transmitters in the director provide electrical transmission of elevation $Vj$, deflection $Dj$, and range $Rj$ spots to the computer.

The stable element is similar to the stable vertical you studied in the second-class qualifications, except that cross level is measured by the outer instead of the inner gimbal. The stable element supplies all of the following mechanically to the computer; level $L$, cross-level $Zd$, and $L+Zd/30$. $Zd$ is also transmitted electrically from the stable element to the director to stabilize the optical units and radar in cross level. The stable element receives director train $B'r$ mechanically from the computer, and own-ship's course $Co$ electrically from the gyro compass.

The computer solves both the antiaircraft problem and the surface problem, which is a special case of the AA problem with target elevation at zero. Inputs to the computer are electrical from the director, ship gyro compass, and pitometer log; mechanical from the stable element; and manual from the computer operators.

The quantities computed and transmitted electrically to the guns are: gun-elevation order $E'g$, gun-train order $B'gr$, sight angle $Vs$, sight deflection $Ds$, fuze-setting order $F$, train parallax for a 100-yard horizontal base $Ph$, and, on

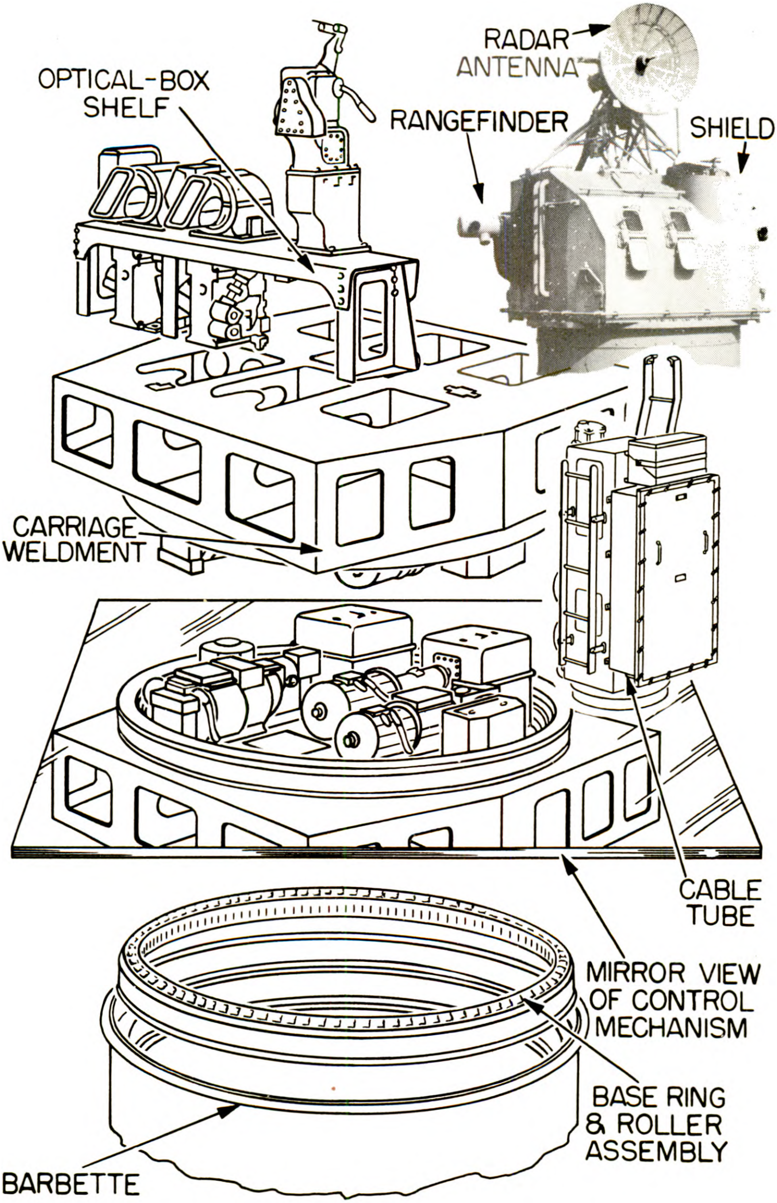


**Figure 5–2.—The basic components of the Mk 37 director.**

carriers, elevation parallax for a 100-yard horizontal base *Pv*.

We have seen how the computer generates changes in range, elevation, and train for the director. These changes are used in conjunction with level and cross-level angles to hold the director telescopes, rangefinder, and radar on target automatically when the computer has a solution.

The flow of information for illumination of the target will be taken up when we study the star-shell computer.

## CONSTRUCTION OF THE MK 37 DIRECTOR

Although the Mk 37 director has many modifications, basically it consists of a slew sight, two director telescopes, a rangefinder and the radar. The slew sight permits rapid

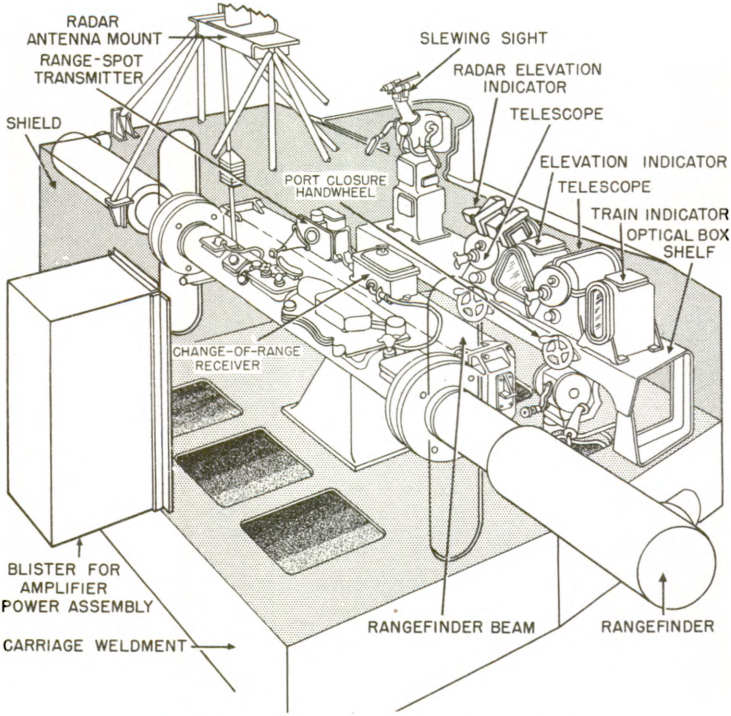


Figure 5–3.—Mounting of the optics in the Mk 37.

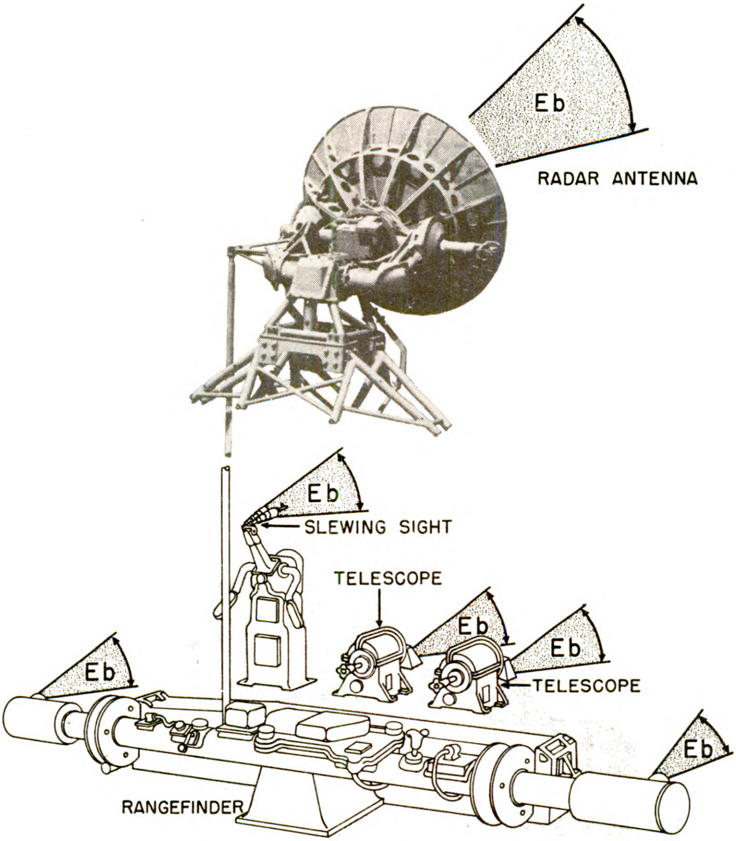


**Figure 5–4.—The lines of sight elevate in synchronism.**

target acquisition, while the optical system and radar establish target position in terms of director train, director elevation, and present range. These instruments, together with numerous others, are mounted on a carriage weldment and are enclosed by the shield as shown in figure 5–2.

The director, with its control mechanisms and cable tube, rotates on a base ring and roller assembly that is supported by a barbette built into the ship's structure. The barbette (also shown in fig. 5–2) is machined parallel to the mean plane of the gun roller paths to reduce roller-path-corrections to a minimum.

The director optics are mounted (fig. 5–3) with their lines of sight parallel to each other in both train and elevation. The telescopes cannot be trained, elevated, or depressed as they are mounted in optical boxes that are rigidly secured to the optical shelf.

Thus the entire director is rotated to place the LOS on target in train. In elevation, the LOS of the telescopes is elevated or depressed by rotation of the small prism inside the pilot housing at the front end of the telescope (fig. 3–2, chapter 3). The elevation gearing moves the lines of sight of the director telescopes, the rangefinder, and the radar antenna simultaneously and in parallelism, as shown in figure 5–4.

The optics and radar antenna of the director are stabilized in cross-level by the input of *Zd* from the stable element.

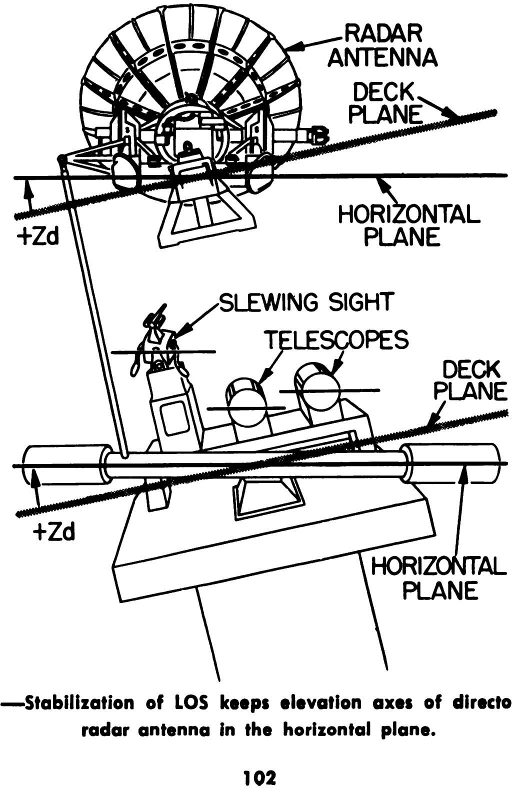


**Figure 5–5.—Stabilization of LOS keeps elevation axes of director optics and radar antenna in the horizontal plane.**

Stabilization of the LOS keeps the elevation axes of the director optics and radar antenna in the horizontal plane, irrespective of deck tilt, as is shown in figure 5–5.

The early Mk 37 directors were equipped with Arma power drives for the train, elevation, cross-level, and parallax drives, but recent modifications are powered by amplidynes. The amplidyne control system of the Mk 37 is explained in OP 1062, so all we will have to do is locate the various units and the connecting shafts.

## THE MK 37 DIRECTOR TRAIN SYSTEM

The units of the train system are shown in figure 5–6. The train amplifier and amplidyne motor-generator are mounted on the cable tube; the train receiver-regulator, power motor,

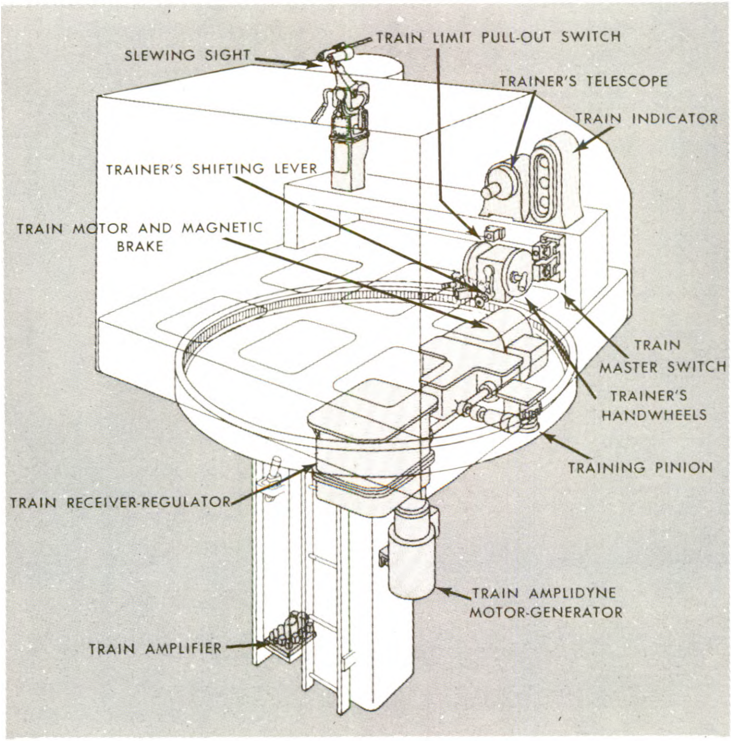


Figure 5–6.—Location of the train equipment for the Mk 37.

and training pinion are on the underside of the carriage weldment. The trainer's handwheels are mounted on top of the carriage weldment, beneath the optical shelf; the slewing sight, trainer's telescope, and train indicator are on the optical shelf.

The trainer can select any one of three types of control—manual, local power, or normal (automatic)—by means of the shift lever shown in figure 5–7.

When the director is in manual control, the train power

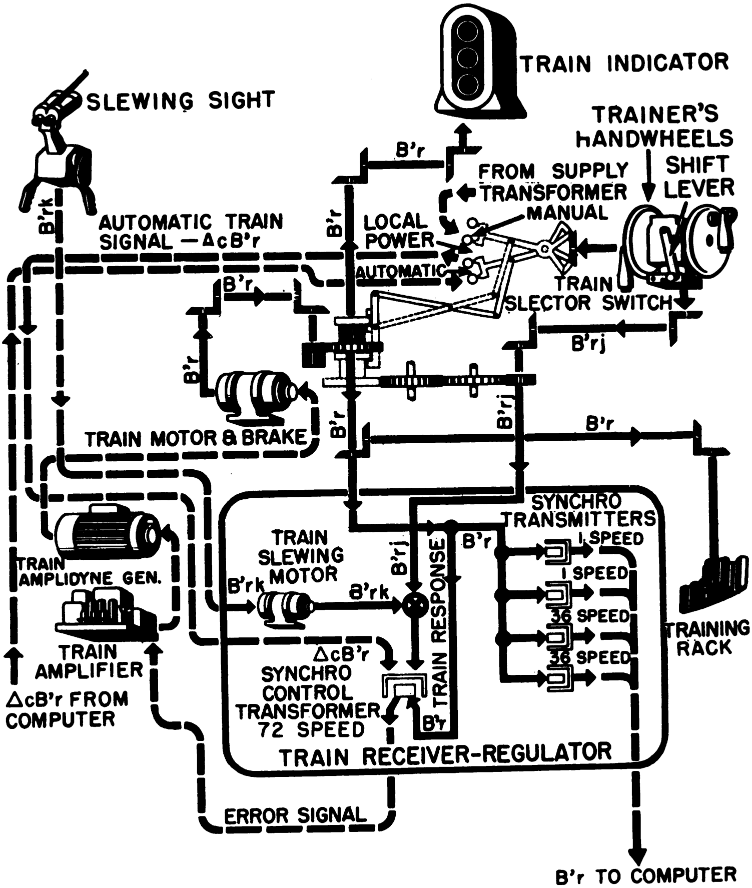


Figure 5–7.—The train control system.

system and slew sight are de-energized. The director is moved by direct gearing from the handwheels to the training pinion, as shown by the dotted line position of the shifting gear in figure 5–7.

In local power control, the shift lever engages the shifting gear with the output shaft of the train motor. At the same time, the stator winding of the synchro control transformer is energized from a local supply transformer through the train selector switch.

As the trainer turns the handwheels he mechanically positions the stator of the *CT*, causing it to generate an error signal in the rotor windings. This error signal is amplified by the amplidyne system and controls the train power motor. The output of the power motor drives the director in train, and feeds back to mechanically reposition the rotor of the synchro control transformer. Notice also that the $B'r$ shaft turns the rotor of two sets of 1- and 36-speed synchro generators that transmit $B'r$ to the computer.

The control officer can also slew the director in train. When he moves the slew sight he simultaneously closes a key (on the handle bars) that actuates a slewing motor. The slewing motor adds a mechanical signal (proportional to the offset of the slew sight) to the handwheel signal in a mechanical differential. The combination of these two signals turns the stator of the synchro control transformer.

Automatic operation—the most important and the primary method of control—is selected by placing the train shifting lever in automatic, as shown in figure 5–7. The shift lever operates the selector switch to establish the electric circuits for normal (automatic) control. Since the train motor is used in both local power and normal operation, the shift lever does not move the shifting gear far enough to disengage it from the train-motor gearing.

With the shift lever in automatic, the director receives the electric order signal $\Delta\ cB'r$ from the computer on the stator windings of the synchro control transformer at 72-speed (1 revolution$=5°$ of train). And, as we have already seen, if the computer has the correct solution, $\Delta\ cB'r$ will keep the

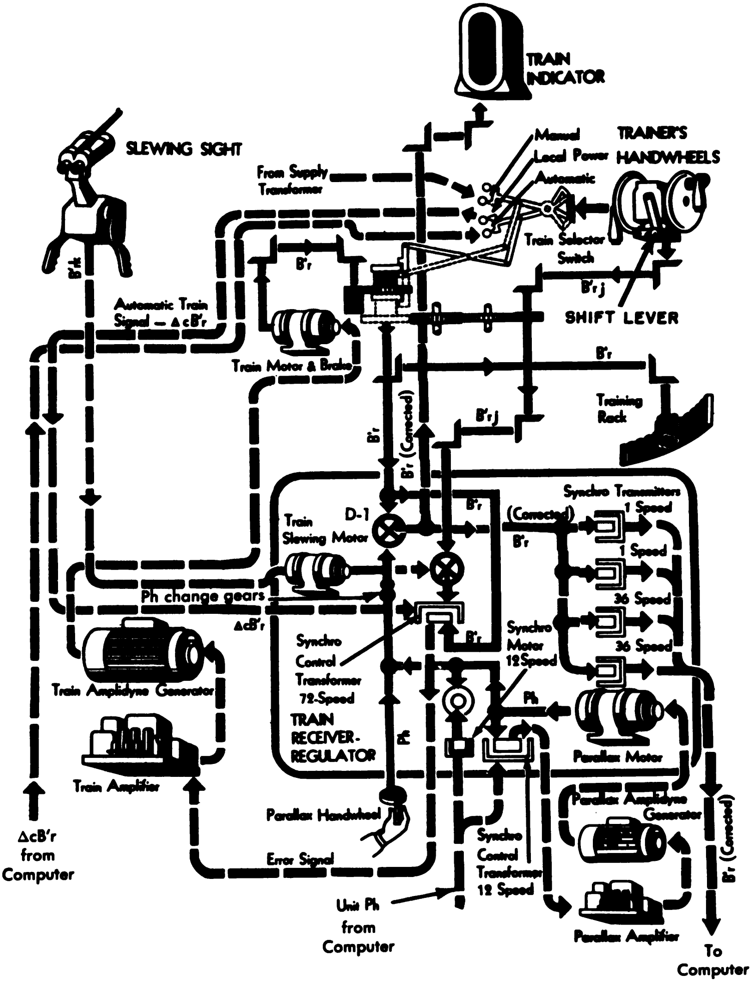


**Figure 5–8.—The train control system (with parallax).**

director on target in train. If the signal is not correct, the trainer can superimpose the handwheel signal Δ $cB'r$ by turning the stator of the *CT*. He can do likewise with the signal from the slew sight.

In chapter 3 we discussed the necessity of correcting $B'r$ for parallax in multiple director installations. Figure 5–8 shows the train control system (with parallax) for such a Mk 37 director.

Unit parallax is received from the computer at 12-speed on a synchro motor and a synchro control transformer. The synchro motor positions the inner dial of a follow-the-pointer dial group used in MANUAL control of parallax. The *CT* is used in AUTOMATIC control of parallax to provide the error signal for the parallax power drive.

In automatic the error signal from the parallax synchro control transformer, through the amplidyne circuit, drives the parallax motor. The output of the motor repositions the rotor of the *CT* and also the outer dial of the follow-the-pointer dial group. Simultaneously a portion of *Ph*,

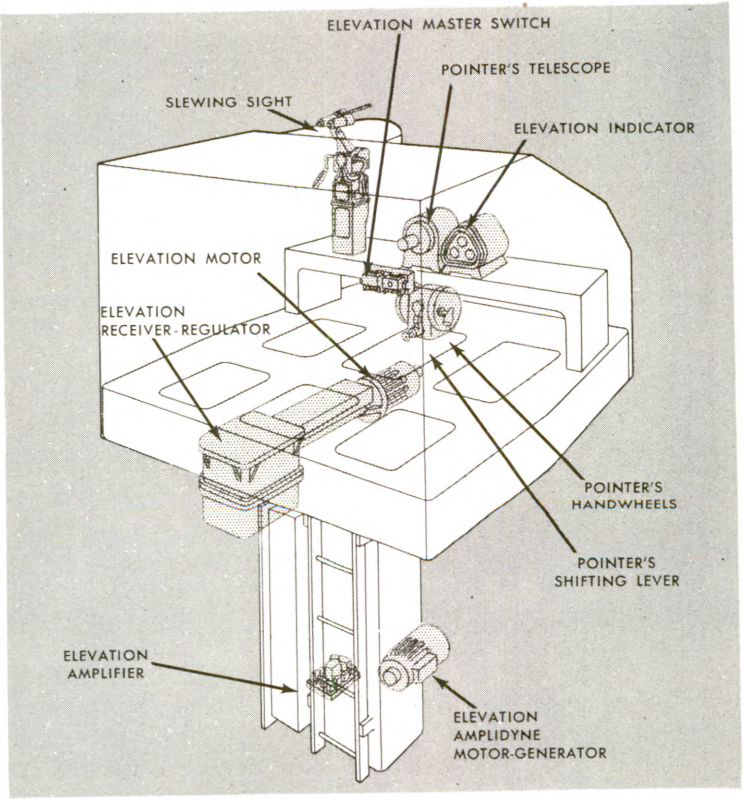


**Figure 5–9.—Location of elevation equipment in the director.**

through the change gears before $D$–1 (fig. 5–8), is corrected for the horizontal distance of the director from the reference point of the ship. This corrected $Ph$ is added to $B'r$ in $D$–1. (Notice that $Ph$ is added to only that portion of $B'r$ used for indicating. The actual position of the director is unaffected by parallax.) The output of $D$–1 positions the dials of the train indicator and the rotors of the two sets of 1- and 36-speed synchro transmitters.

Thus when the director is on target, the value of $B'r$ actually shown on the train indicator and transmitted to plot is that value of $B'r$ which would be transmitted from a director located at the reference point of the ship.

Manual operation of the $Ph$ system is accomplished by engaging the $Ph$ handwheel and matching the parallax follow-the-pointer dials. In the event of failure of the automatic $Ph$ system, the control officer's talker is usually assigned to operate the $Ph$ handwheel.

The units of the elevation system are located as shown in figure 5–9. The power requirements of the elevation system are less than for train; otherwise the operation of the two systems is similar. The three methods of control used in train are also available in elevation, and are selected in a similar manner by a shift lever on the pointer's handwheel bracket.

Notice in figure 5–10 (the elevation control system) that the stator winding of the synchro control transformer (72 speed) is energized in automatic through the elevation selector switch by $\Delta\ cEb+Zd/30$ from the computer. The function of cross level, you remember, is used to null the elevation effect of cross level on the telescopes and rangefinder.

Director elevation $Eb$, however, is required for the elevation indicator transmitters, and for the slew sight. $Eb$ is obtained by gearing down a portion of the output of the cross-level motor to $Zd/30$ and subtracting it from $Eb+Zd/30$ in a mechanical differential. This arrangement provides smooth operation in AUTOMATIC, which is the normal method of control. If the elevation system were used in local with cross level in automatic, however, the pointer

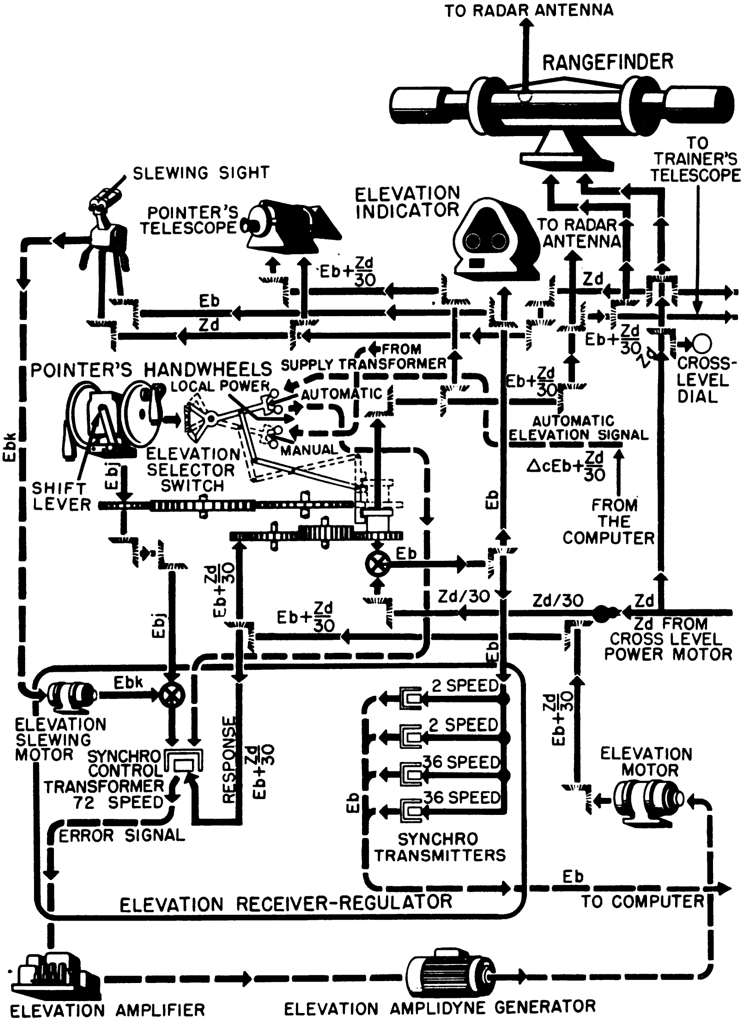


Figure 5–10.—The elevation control system.

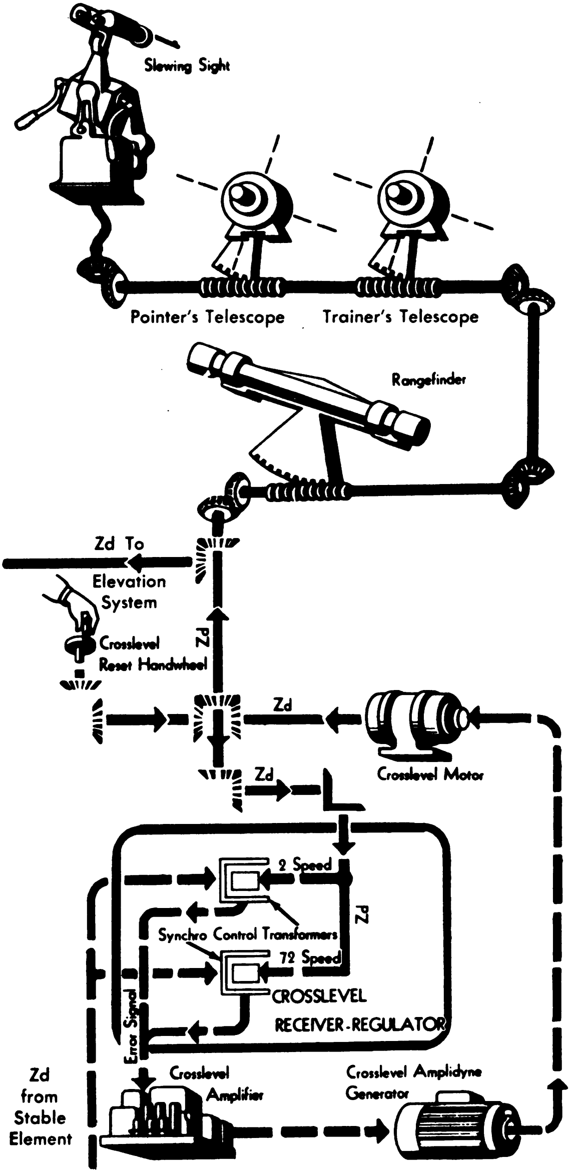


Figure 5–11.—The cross-level control system.

would have to null the effect of cross level on elevation with his handwheels.

## THE MK 37 DIRECTOR CROSS-LEVEL SYSTEM

The operation of the director cross-level system is shown schematically in figure 5–11. The cross-level receiver-regulator and motor are mounted on the underside of the carriage weldment in a manner similar to that of the elevation components. The cross-level amplidyne is mounted below the elevation amplidyne on the cable tube; the cross-level amplifier is in the control panel with the train and elevation amplifiers.

The operation of the cross-level system differs in several respects from either train or elevation. The cross-level power drive is designed for automatic operation only. In the event of a casualty, the only alternative is to reset the cross-level system to zero by means of the reset handwheel shown in figure 5–11.

A second difference is the *Zd* transmission system. Two synchro control transformers (2- and 72-speed) are used instead of the single units (72-speed) employed in train and elevation. *Zd* represents an exact position angle and the director cross-level system must be in exact synchronism with this angle. If only a 72-speed synchro control transformer were used, the cross-level system would synchronize with the incoming signal at the nearest 5° position.

In the train and elevation systems, however, the signals from the computer drive in the director at rates corresponding to $\Delta\ cB'r$ and $\Delta\ cE+L+Zd/30$ respectively. The initial position of the line of sight is established by the pointer and trainer. Therefore, only 72-speed synchro transmission systems are required.

# QUIZ

1. What are the three main components of the gun fire-control system Mk 37?
2. Which component is considered as the control center of the system?
3. What three quantities are measured by the director?
4. What is meant by a dual purpose GFCS?
5. Name six quantities that may be transmitted by the Mk 1A computer.
6. What is the essential difference between the stable element and stable vertical?
7. What three types of operation are provided in the director for train and elevation?
8. How are the optics and radar antenna of the director stabilized?
9. When the control officer closes the slewing switch on the handle bars of the slewing sight, he actuates the
   a. clutch.
   b. amplidyne.
   c. amplifier.
   d. slewing motor.
10. The most recent modifications of the Mk 37 directors are powered by what system?
11. Unit parallax can be introduced in the director in
    a. manual.
    b. automatic.
    c. manual or automatic.
    d. local or automatic.
12. How is the desired method of control for train and/or elevation selected?
13. What are the three main control units mounted on the underside of the director carriage weldment?
14. The *Zd* power drive is designed for what type of operation?

# CHAPTER 6

## THE AA FIRE-CONTROL SYSTEM—THE COMPUTER

The purpose of this chapter is to help you understand the total operation of the Mk 1A computer—the relationship between the basic mechanisms, the method the instrument uses to solve the problem, and its relationship to the director and stable element. Once you have gained this understanding, the adjustment and maintenance procedures outlined in the OP's will be easier to understand and follow. And last, but not least, this chapter brings you up to date on the Mk 1A by describing the most important changes authorized by NavOrd Ordalts 2331A, 2332, 2336, 2339, 2620, 2626, 2894, 2963, and 3091. The changes authorized under these ordalts are of such extent that the designation of Computer Mk 1 is changed to Computer Mk 1A after they have been made. These changes modernize the instrument in the following respects.

1. Improve the antiaircraft performance of the computer by replacing the North-South vector rate control mechanism of the Computer Mk 1 with a target vector rate control mechanism.
2. Double the limits of target speed and rate of climb.
3. Change the ballistic quantities used in all computers having 5″/38 cal. ballistics to correspond with revised 5″/38 cal. ballistic data contained in OP 551A, dated 11 February 1946.
4. Provide transmission of target elevation angle (*E*) from a potentiometer and from a synchro transmitter.
5. Provide computer control circuit changes which improve the operation of the instrument and reduce the task of the operating crew during rate control.

The major part of the description of Computer Mk 1 given in OP 1064 is applicable to Computer Mk 1A. The important features wherein Computer Mk 1A differs from Computer Mk 1 as described in OP 1064 are treated in this chapter as has been stated. For the COMPLETE treatment, refer to OP 1064, Computer Mk 1A, Addendum No. 1.

The majority of the controls for the Mk 1A are shown in figure 4–1. Frequent reference to this illustration will help you associate the controls shown on the schematic diagram with the actual equipment. In addition to figure 4–1, close-ups of the individual dial groups will be shown from time to time during the following discussion.

Much of this chapter depends on the schematic diagram of the Mk 1A computer. For this reason it is advisable, if possible, to refer to this schematic which is figure 24 of OP 1064, Computer Mk 1A, Addendum No. 1. In the event this publication isn't immediately available, for the most part you can follow the schematic diagram of the Mk 1 Computer in OP 1064.

The content of this chapter is divided into two major sections corresponding to the two major sections of OP 1064 and having the same designations, viz, General Description and Operation. The General Description given in OP 1064 is applicable to Computer Mk 1A when modified as indicated in the General Description section of this chapter. The headings used in this section of the chapter correspond to those under which the same features are described in OP 1064. This is not exactly true for the Operation Section, but the system has been followed as closely as possible in that section also.

## GENERAL DESCRIPTION

All modifications of Computer Mk 1A (fig. 4–1) are essentially the same in appearance, function, and operation. They differ mainly with respect to the self-contained ballistic data which adapt them to particular guns. The mod numbers vary according to the guns to be controlled as follows:

| | |
|---|---|
| Mods 8, 12, 17, and 18 | 5″/54 cal. |
| Mods 13 and 19 | 5″/38 cal. |

| | |
|---|---|
| Mods 14 and 16 | 6″/47 cal. |
| Mod 15 | 8″/55 cal. |

Mods 8 to 16 inclusive are covered in this chapter.

Mods 17 to 19 are in the design stage and sufficient information is not available for their inclusion. Mods 17 and 19 are to be used in Gun Fire-Control System Mk 67 as follows:

a. Mod 17 in GFCS Mk 67 Mod 0, which has the usual 60 cycle synchro transmission system.

b. Mod 19 in GFCS Mk 67 Mod B, which provides for the use of 400 cycle supply in a large part of the synchro transmission system.

The difference between the Computer Mk 1 and the Mk 1A can be generalized as follows:

1. The dials and gearing have been altered to make the limits of operation of the ship speed, target speed, rate of climb, and wind speed inputs of Computer Mk 1A twice the values of those in Computer Mk 1. Computer Mk 1A, therefore, can be operated effectively against modern aircraft.

2. The rate control mechanism is changed. It differs functionally; components of target motion are taken along and at right angles to the line of sight rather than with respect to a North-South axis. One of the principal mechanical differences is the elimination of the vector solver, which was made possible by the functional change. Another mechanical difference is the addition of a rate of climb ($dH$) follow-up. The sensitivity of the mechanism has been increased, or, stated another way, the time constant, which is the time required to reduce an error to 37% of its initial value, has been decreased. Greater flexibility of operation is obtained by the addition of a means whereby the time constant can be varied at the will of the operator.

3. A number of automatic operating controls have been added, resulting in more satisfactory operation of the gun fire-control system as a whole, and in simplification of the task of the computer operating crew.

4. An additional *I. V.* correction is applied in the predictor

section of Computer Mk 1A Mods 13, 14, 15, and 16 by means of an *I.V.* knob on the front of the computer.

5. Certain servo motor circuits have been modified to reduce oscillations in the fuze ($F$), and gun elevation order ($E'g$) outputs.

6. The fuze computation network has been changed.

7. In Computer Mk 1A Mods 8 and 12, provision is made for obtaining superelevation for ranges beyond 20,000 yards in surface fire.

8. All mods of Computer Mk 1A transmit target elevation ($E$) in two ways: by synchro transmission, and through the output of a potentiometer.

9. Computer Mk 1A Mod 15 computes and transmits values of parallax range instead of parallax in elevation due to a horizontal base ($Pv$). All of these features are dealt with in detail later.

## BASIC MECHANISMS

In general, Computers Mk 1 and 1A contain the same types of basic mechanisms, but they do not contain the same number of each type. The principal differences are the elimination of the vector solver and the addition of a time delay relay (agastat). Where basic mechanisms have been added or removed in converting a Mk 1 to a Mk 1A, the fact will be indicated in the pertinent descriptive material.

## TYPES OF TARGETS AND ATTACK

Computer Mk 1A produces gun orders for combatting the same types of targets and attack as does Computer Mk 1. However, it should be noted that Computer Mk 1A can be operated successfully against targets having twice the maximum horizontal and vertical speeds as Computer Mk 1. As an example, Computer Mk 1A computes gun orders for continuous fire against dive bombers attacking other ships when the vertical component of target speed is as much as—500 knots, in contrast to the previous maximum rate of—250 knots.

## AUTOMATIC FIRE CONTROL IN THE GUN DIRECTOR MK 37 SYSTEM

The description under this heading in OP 1064 applies to Computer Mk 1A except for that portion given under item 4 "Correcting the target motion estimates." When operating Computer Mk 1A, it is unnecessary for the computer crew to apply estimates of target motion (either initial or corrective). Horizontal target speed (*Sh*) and rate of climb (*dH*) are automatically brought to zero when the computer time motor is stopped. As soon as the computer is engaged in the tracking problem (starting the time motor), target course (*Ct*) is slewed to the proper quadrant for tracking, and *Sh* and *dH* are brought to their computed values automatically. Thus, the proper values of target motion are established to produce accurate outputs of generated range, elevation, and bearing.

## TRACKING THE TARGET

The description given under this heading in OP 1064 is entirely adequate for Computer MK 1A with one exception, which is that the computer crew need not apply estimates of target motion when in automatic (normal) control.

It should be noted that provision has been made in Computer Mk 1A for the increased speeds of targets. This is accomplished by doubling the values of the target speed, rate of climb, ship speed, wind speed, and related shaft lines in the control section, and changing the target diving speed, ship speed, wind speed, and rate of climb dials.

## INPUTS AND OUTPUTS OF THE COMPUTER MK 1A

The inputs to Computer Mk 1A are the same as those for the Computer Mk 1. It should be noted, however, that for Computer Mk 1A, the target motion inputs *Sh*, *dH*, *A*, and *Ct* are as described under the above heading in OP 1064 only during local control. In Computer Mk 1A, these quantities are determined mechanically in the instrument during normal control.

The outputs are the same except that Computer Mk 1A (all mods) has an additional output of target elevation (*E*), and the Mod 15 has parallax range instead of *Pv* as an output.

Target elevation (*E*) is transmitted electrically from a potentiometer and from a synchro unit. The potentiometer supplies information to Indicator Mk 22 Mod 0 in Radar Equipment Mk 25 Mod 2 for use during target acquisition. The synchro signal is available for use in target practice analysis.

## OPERATION

### OPERATING CONTROLS

The arrangement of dials, handcranks, and switches of Computer Mk 1A is the same as that of Computer Mk 1, with the following exceptions:

1. The rate of climb handcrank has been relocated. The radar range receiver has been removed, and the rate of climb handcrank is located in the cover opening previously occupied by the radar range receiver window.
2. The time motor switch has been removed, and a time motor push button installed adjacent to the target speed dial group.
3. A sensitivity push button and an air-surface selector switch have been added at the elevation station.

[Note] The locations of the operating controls mentioned in items 1, 2, and 3 are indicated in figure 4–1.

4. Three vernier dials have been added to increase the accuracy with which test problems can be set up. These are for range (*R*), target angle (*A*), and rate of climb (*dH*).

Operating dials and counters are the same as those on Computer Mk 1, except that some can indicate double their former values in order to permit tracking of targets having greater speeds.

#### The Dials on the Front of Computer Mk 1A

The Target and Ship Dial Group (see fig. 6–1) has been altered as follows:

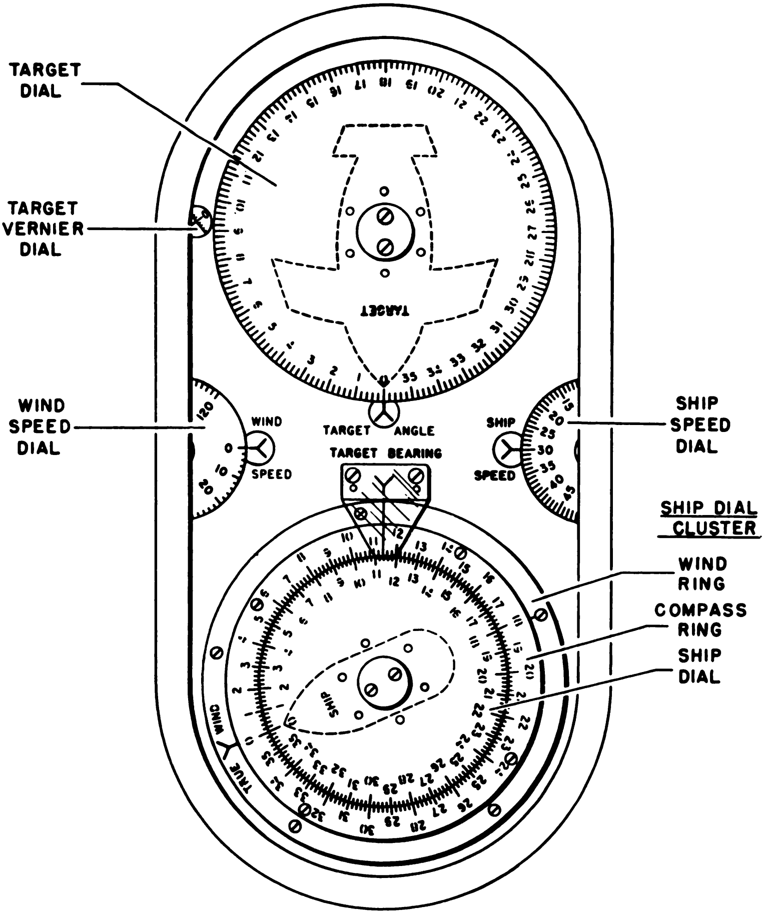


Figure 6–1.—Target and ship dial group.

1. The target dial gearing is equipped with a vernier dial that indicates target angle in tenths of a degree. The vernier dial is primarily for test purposes.

2. The wind speed dial is graduated from 0 to 120 knots.

3. The ship speed dial is graduated only from 0 to 50 knots, but can make a complete revolution, representing 90 knots.

The Target Speed Dial Group is shown in figure 6–2. The

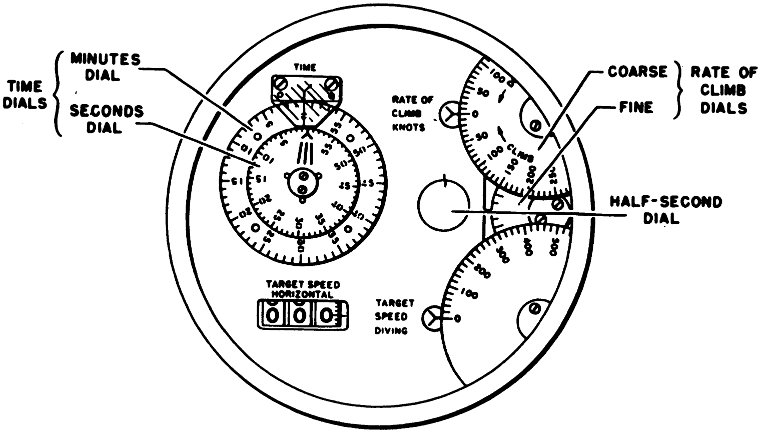


Figure 6–2.—Target speed dial group.

target speed counter shows horizontal ground speed of the target ($Sh$) in knots, from 0 to 800 knots.

The rate of climb dials show rate of climb ($dH$) in knots. The coarse dial is graduated every ten knots from DIVE 500 knots through 0 to CLIMB 300 knots. A fine dial graduated every five knots, but unnumbered, has been added in Computer Mk 1A. When reading intermediate values on the fine dial, it should be noted that it turns in a direction opposite to that of the coarse dial.

The target speed diving dial shows diving speed ($Ss$). The dial is capable of rotating from 0 to ±900 knots. However, since its primary purpose is to indicate diving speed (negative range rate), only the DIVE (minus) part is graduated and numbered. The graduations are at 20-knot intervals.

The Range Dial Group is the same as that of Computer Mk 1 except that the radar range dial and receiver are not included in the Mk 1A.

The range gearing of Computer Mk 1A is equipped with a vernier range dial. The vernier dial is located behind the threaded plug located in the side of the cover just below the range receiver dials. By means of the vernier, which has graduations at 5-yard intervals, range can be read or set to the nearest yard during test procedures.

### Time Motor and Power Switch

A push button, located at the range station, has been substituted for the time motor switch, which has been removed from the computer. Operation of the new arrangement is given under the heading, "The Controls at the Range Station."

The power switch is unchanged.

### Initial Velocity and Dead Time

Computer Mk 1A Mods 13, 14, 15, and 16 have two sets of initial velocity dials and knobs. One set is located on the lower left side, as in the Computer Mk 1. The other set is located on the lower front side. Both sets are identical. These dials show the value of initial velocity (*I. V.*) set into the computer. They are graduated in feet per second from:

2350 fs to 2600 fs for Mod 13
2250 fs to 2720 fs for Mods 14, 16
2400 fs to 2700 fs for Mod 15

Values of initial velocity are properly set into the computer only when both dials read alike. A legend plate stating this is located above the front *I. V.* dial.

The initial velocity dial and knob arrangement for Computer Mk 1A Mods 8 and 12 is the same as that of Computer Mk 1. The *I. V.* dial of Mods 8 and 12 is graduated in feet per second from 2400 fs to 2650 fs.

The dead time dial and knob are the same as those for Computer Mk 1.

### Controls—Front of Computer Mk 1A

The controls on the front of Computer Mk 1A include the controls of the target and ship group, and those of the range station, the bearing station, and the elevation station. Differences between the controls and the description given in OP 1064 are set forth below.

THE CONTROLS IN THE TARGET AND SHIP GROUP are described in OP 1064. The description adequately covers this group for Computer Mk 1A.

THE CONTROLS AT THE RANGE STATION, as described in OP 1064, are the same for the Computer Mk 1A except:

The control switch, Computer Mk 1A, has three positions which are labeled NORMAL, TEST, and LOCAL instead of AUTO, SEMI-AUTO, and LOCAL.

With the control switch at NORMAL, bearing and elevation corrections are made automatically on signal from the trainer and pointer in the director.

With the control switch at TEST, no rate corrections can be made with the generated elevation and generated bearing cranks, as formerly. These cranks, whether IN or OUT, merely turn the generated elevation and generated bearing dials.

With the control selector at LOCAL, the rate control mechanism is inoperative. This type of operation is used against surface targets when the director is not operating.

THE RANGE RATE CONTROL SWITCH description as given in OP 1064 is applicable to Computer Mk 1A if it is borne in mind that there is no semi-auto control of Computer Mk 1A.

THE RANGE TIME CONSTANT KNOB is called the range rate ratio knob on Computer Mk 1. The only identification appearing on it in Computer Mk 1A is the legend, SECONDS TIME CONSTANT, on the sleeve. The sleeve is graduated to indicate seconds (time constant), from 0 to 16, in 2-second intervals. The knob must be IN to make and hold a setting. Rotation of the knob in the IN position is limited from 1 (approximately) to 16 seconds. The value set at the knob indicates the time, in seconds, required for the range rate control mechanism to reduce a range rate error to approximately 37% of its initial value. For example, if range rate is in error by 150 knots and the knob is set at 2, in two seconds the range rate error will have decreased to approximately 55 knots. The OUT position is provided only to permit removal of the cover for adjustment or repair.

THE TIME PUSH BUTTON in Computer Mk 1A is located beside the time dials and adjacent to the range rate control manual push button (see fig. 4–1). The time motor can be stopped or started by momentarily depressing the button.

THE CONTROLS AT THE BEARING STATION description given in OP 1064 is applicable to Computer Mk 1A with the exceptions given below.

The generated bearing crank, since there is no semi-automatic control, can be placed in the IN or OUT position. (The gear for receiving hand inputs has been removed from the *jBr* line.)

THE CONTROLS AT THE ELEVATION STATION consist of the generated elevation crank, the rate of climb handcrank, the air-surface switch, and the sensitivity push button. The location of the generated elevation crank is the same as for a Computer Mk 1. The other three controls are located as indicated in figure 4–1.

The function of the GENERATED ELEVATION CRANK is the same as described in OP 1064 for Computer Mk 1 with the exception that, there being no semi-auto control, no elevation rate corrections are introduced by the knob, and the knob can be left IN or OUT. (The gear for receiving hand inputs has been removed from the *jE* line.)

THE RATE OF CLIMB HANDCRANK has two operating positions, HAND and AUTO, selected by means of a lever. When the lever is at the HAND position, the handcrank is connected to the rate of climb gearing, allowing values of rate of climb to be put in manually. Shifting the lever to AUTO disconnects the handcrank from the rate of climb gearing and closes a switch that energizes the *dH* follow-up. In this condition, values of rate of climb are changed automaticaly by corrections coming from the rate of control mechanism.

THE AIR-SURFACE SWITCH, as the name implies, has two positions, AIR and SURFACE. It should be set at AIR for an air target, and at SURFACE for a surface target. When so positioned it adapts the operation of the sensitivity control system to the particular type of target.

THE SENSITIVITY PUSH BUTTON provides a means of varying the action of the sensitivity mechanism of the Computer Mk 1A. The push button controls a switch that is normally closed. Depressing the push button opens the switch and causes the sensitivity mechanism to assume the position of maximum sensitivity. The mechanism is held in this position for a pre-set delay time after the push button is released, and then returns to the normal position.

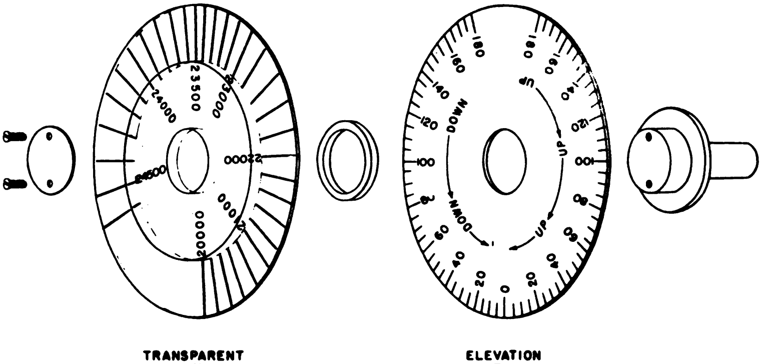
## Handcranks and Dials—Rear Top

The handcranks and dials on the rear top of Computer Mk 1A Mods 13, 14, 15, and 16 are the same as those for Computer Mk 1. On Computer Mk 1A Mods 8 and 12, a dial has been added to the spot dial group.

The Spot Group of Computer Mk 1A is identical with that of Computer Mk 1 except for the elevation spot dial used in Computer Mk 1A Mods 8 and 12. In these modifications a transparent dial (fig. 6–3) is secured directly over the *Vj* dial, on the same hub. The transparent dial is graduated in terms of range from 20,000 yards to 24,600 yards. The 20,000-yard graduation is alined with the 0-graduation of the *Vj* dial. The spacing between each succeeding pair of graduations increases with range, as indicated in figure 6–3.

In the computer, the output of the superelevation cam is limited to values corresponding to a maximum range of 20,000 yards. However, at low position angles the extreme range of the guns exceeds this value.

When firing against surface targets at ranges beyond 20,000 yards, additional superelevation can be set into the



TRANSPARENT OVERLAY DIAL

ELEVATION SPOT DIAL

Figure 6–3.—Elevation spot dials.

instrument by means of the elevation spot knob. The correct amount to be set in is determined by means of the transparent range spot dial. The spacing of the graduations on this dial corresponds to the additional superelevation required for values of range beyond 20,000 yards. Therefore, when the transparent dial is set at a selected value of range, an amount of elevation spot ($Vj$) is introduced which will supply the additional superelevation required for that extended value of range.

### The Target Course Indicator

The description of the target course indicator in OP 1064 is applicable except that the target signal light is omitted from Computer Mk 1A.

### The Star Shell Computer

The operating controls for the various modifications of star shell Computer Mk 1 are described in OP 1064. While Mod 3 is not specifically mentioned in OP 1064 because it was not designed at the time of writing, the controls for this mod are the same as for Mods 1 and 2.

It should be noted here that the knob designated STAR SHELL RANGE on the Mod 0 is replaced by a handcrank on the other mods. This handcrank is designated FUZE RANGE. Likewise, the knob designated STAR SHELL RANGE SPOT on the Mod 0 is designated as STAR SHELL RANGE on Mods 1, 2, and 3. Despite the two changes in designation, the functions of these knobs are unchanged.

Mods 1, 2, and 3 instruments have two additional handcranks: the deflection handcrank, and the elevation handcrank. These handcranks are used to position elevation and deflection spot and search dials, which have also been added.

## OPERATING INSTRUCTIONS

The automatic tracking controls incorporated in Computer Mk 1A as a result of Ordalt 2626 cause its operation to differ considerably from that of Computer Mk 1. Therefore the operator should familiarize himself with these devices as described in chapter 4 and as shown schematically in figure 4–10. The operating instructions for Computer Mk 1A differ from those for Computer Mk 1, as noted in the following descriptions.

### The Conditions of the Computer

The statements appearing under this heading in OP 1064 are applicable to Computer Mk 1A except for those pertaining to basic types of operation. Computer Mk 1A has three basic types of operation: NORMAL, which is similar to AUTOMATIC for Computer Mk 1; and LOCAL and MANUAL which are the same as for Computer Mk 1.

### Types of Operation

The description given in OP 1064 under the heading "The Types of Operation" is applicable to Computer Mk 1A only to the extent defined in the following description. It should be noted that there is no semi-automatic operation of Computer Mk 1A.

In normal operation, the rate control group computes corrected values of $Sh$, $dH$, and $A$. It does not function in test or local operation.

NORMAL OPERATION. The description of automatic operation in OP 1064 adequately describes normal operation for Computer Mk 1A.

SWITCH POSITIONS:

Control switch at NORMAL.

Range rate control switch at AUTO or MANUAL

MANUAL OPERATION. Manual operation is described adequately in OP 1064.

SWITCH POSITIONS:

Control switch at TEST

Range rate control switch at MANUAL

LOCAL OPERATION. This is the same as described in OP 1064 for Computer Mk 1.

SWITCH POSITIONS:

Control switch at LOCAL

Range rate control switch at MANUAL

## Instructions for Operating Computer Mk 1A

Operation of Computer Mk 1A differs from that of Computer Mk 1 in such important respects as:

a. There is no semi-automatic control.

b. In setting up for normal (automatic) operation it is not necessary to apply inputs of estimated target angle, target speed, and rate of climb. Neither is it necessary for the computer operator to apply range inputs nor match the range dials during the search and tracking periods.

c. The computer time motor can be started from the director. Because of the extensive differences between the operation of Computers Mk 1 and Mk 1A, the operating instructions given in OP 1064 are NOT APPLICABLE to Computer Mk 1A except as specifically noted below.

### SECURED CONDITION

The nature of this condition is such that the instructions given in OP 1064 are applicable for Computer Mk 1A except that the following specific exceptions should be noted for the Mk 1A:

### Securing the Computer Mk 1A.

AT THE RANGE STATION:

1. Stop the time motor by depressing the time motor push button.

### Set the Handcranks and Dials in Secured Condition.

AT THE RANGE STATION:

1. Turn the control switch to NORMAL.
3. Turn the range rate control switch to AUTO.
5. Set the target speed handcrank selector at AUTO.
6. Set the range time constant knob at 16.

AT THE ELEVATION STATION:

1. Set the rate of climb handcrank selector at AUTO.
6. Pull the initial velocity knobs out; set *I. V.* according to mod, as follows:

| MOD | *I. V.* |
|---|---|
| 8 & 12 | 2550 fs |
| 13 | 2500 fs |
| 14 & 16 | 2565 fs |
| 15 | 2600 fs |

8. Set air-surface switch at AIR.

AT THE BEARING STATION:

4. Set the target angle handcrank at AUTO.

AT THE OTHER STATIONS:

4. With the star shell fuze range handcrank IN, set the inner dial at 10,000 yards. Pull the handcrank OUT and set the outer dial at 10,000 yards. Push the handcrank IN.

### STANDBY CONDITION

Initial standby, standby for search, and standby during search, are the same as described in OP 1064 for Computer Mk 1.

The procedure for changing from secured condition to standby for search and standby during search is as described in OP 1064 except that the control switch of Computer Mk 1A is set at NORMAL.

NOTE: In Computer Mk 1A Mods 13, 14, 15, and 16, both initial velocity dials should be set at the ordered value of *I. V.*

### STANDBY FOR AN AIR TARGET

When changing from standby during search to standby for an air target, the following is accomplished:

AT THE ELEVATION STATION:

1. With the ship speed handcrank at IN set in the correct value of ship speed ($So$), then set the ship speed handcrank at OUT. Note that $So$ continues at the correct value.

2. With the wind speed handcrank, set in wind speed ($Sw$).

3. Check that dead time (*Tg*) and initial velocity (*I. V.*) are at their ordered values.

AT THE BEARING STATION:

1. With the wind direction handcrank, set in wind direction (*Bw*).

AT OTHER STATIONS:

1. Connect, synchronize, and lock the selector drive.

4. Pull spot knobs OUT, noting that correct values of *Rj*, *Vj*, and *Dj* are indicated.

## Automatic Operation

Computer Mk 1A is ready for automatic operation when properly set up for standby. Automatic operation commences as soon as the time motor is started. The normal procedure for starting the time motor is for the trainer to close his signal key; but the time motor can also be started by depressing the TIME push button on the computer.

In automatic (normal) operation, the Computer Mk 1A will commence tracking when the trainer depresses his signal key, thus starting the computer time motor and closing the rate control clutches. During automatic (normal) operation, the following differences from OP 1064 or the Mk 1A Computer should be noted.

AT THE RANGE STATION:

1. Keep the setting of the range time constant knob as low as possible without causing instability.

2. Computer Mk 1A matches *cR* with *R* automatically. If the range dials are out of synchronism and do not approach agreement with sufficient rapidity, they can be brought into synchronism more rapidly by momentarily shifting the range time constant knob to a high value. It should be noted that the range dials can also be matched by rotating the generated range crank in the OUT position.

AT THE ELEVATION STATION:

1. If range is below 8,000 yards and the target maneuvers radically (the solution indicators spin), momentarily press the sensitivity push button.

## MANUAL OPERATION AGAINST AN AIR TARGET

This type of operation for Computer Mk 1A is the same as that described in OP 1064 for Computer Mk 1.

## STANDBY FOR A SURFACE TARGET

Standby for a surface target is the same as standby for an air target (as described in this chapter) with the following exceptions:

AT THE RANGE STATION:

Note should be taken of the setting of the time constant control transmitter. This setting is normally made as a matter of adjustment procedure, the value of the setting being determined by doctrine.

AT THE ELEVATION STATION:

4. Set the air-service switch at SURFACE.

## AUTOMATIC (NORMAL) OPERATION (SURFACE TARGET)

Computer Mk 1A differs from Computer Mk 1 in that it can be operated against high speed (15 knots or higher) surface targets in normal (automatic) control. For low speed surface targets, manual rate control should be used. Tracking in automatic operation against a surface target is similar to that described for an air target. As long as the *dH* handcrank is kept at AUTO, the low elevation switch causes *dH* to be kept at zero in the instrument.

## LOCAL OPERATION

The procedure for local operation is the same as described in OP 1064.

## MAIN BATTERY OPERATION

The use of Computer Mk 1A for main battery operation is the same as described in OP 1064 for Computer Mk 1. Operation of the Mk 1A is, of course, limited to automatic, local, and manual control.

## OPERATING CAUTIONS

The operating cautions given in OP 1064 for Computer Mk 1 are applicable to Computer Mk 1A, except for those pertaining to semi-auto operation. However, where limits are specified, the new limits of Computer Mk 1A should be substituted. Likewise, under the subheading "Setting *I. V.*," the design *I. V.* of the mod being considered should be substituted for the 2550 fs value given in the OP.

It should be noted that Mods 13, 14, 15, and 16 instruments have two *I. V.* dials. The computer is not properly set up unless these dials are in agreement.

## PREDICTION SECTION

The material included under the Prediction Section in OP 1064 applies generally to the Computer Mk 1A. However, some additional information must be presented in order to cover changes made in the Computer Mk 1 since the OP was published. These changes were made chiefly in dead time range prediction, initial velocity correction, and in the arrangement of the fuze ballistic computer. Certain other material is included here to cover new modifications of the computer.

It has been shown that, to provide for increased target speed, shaft values in the relative motion and integrator groups were doubled. This causes the inputs of *Xo*, *Yo*, *Sw*, *RdBs*, and *RdE* to be applied in the prediction section at double the shaft values formerly used in Computer Mk 1. This is desirable insofar as operation of the prediction multipliers is concerned. By doubling the values of the rack inputs to the prediction multipliers, the values of the multiplier outputs are doubled, i. e., the full travel of the output rack represents twice the prediction in Mk 1A that it did in Mk 1. This makes it possible to obtain predictions corresponding to the increased target speeds. However, before applying the prediction multiplier outputs to the rest of the prediction mechanism, the shafting must be restored to the original value per revolution, otherwise it would be necessary to redesign the rest of the prediction mechanism (including the ballistic cams). This restoration is accomplished by installing halving gear ratios in the multiplier output lines. Beyond the points where these gears are installed, the prediction mechanism shafting moves the same amount as previously for a given change of rate input. The correct numerical values are thus registered on the advance range, sight angle, and sight deflection counters.

The changes made in the relative motion group doubled the value of the $WrD+KRdBs$ shaft lines. To offset the effect of this change, the gearing in the input to the follow-up was changed to restore the follow-up to its former value per revolution. This was necessary because the star shell computer was not affected by the conversion ordalts.

## Computing Advance Range, *R2*

The description contained in OP 1064 under Computing Advance Range applies to Computer Mk 1A with the following exceptions:

THE RANGE PREDICTION MULTIPLIER. It is stated in OP 1064 that the sum of $cR$ and $Rt$, as obtained in the range prediction multiplier system, gives an accurate value of advance range ($R2$); when wind is zero the value of *I. V.* applied in the instrument is 2550 fs. This is true only for Mods 8 and 12 of Computer Mk 1A, because these are the only ones having such a value for design *I. V.* The design *I. V.*'s of other mods of Computer Mk 1A are listed under the heading "Initial Velocity" in this chapter. When the *I. V.* set into the instrument corresponds to the design *I. V.* listed for that particular mod, the value of $R2$ obtained as described above is correct.

THE $Tf$ BALLISTIC COMPUTER. The following feature, which has the effect of reducing oscillations in $R2$, $F$, and $E'g$, has been incorporated in Computer Mk 1A Mod 13. Without this feature, undesirable oscillations could occur whenever the problem set in the computer involved high negative range rates. The size of the permanently connected capacitor on the $Tf$ servo motor has been reduced to one mfd. In addition, a 4-mfd capacitor is provided. This capacitor is connected to the motor through a microswitch which is actuated by a cam mounted on the comparison differential spider shaft. When the spider is one-third of a revolution from the synchronized position, the switch is closed, and the 4-mfd capacitor is cut into the *Tf* servo motor circuit.

### The Elevation Prediction Network

The elevation prediction network in Computer Mk 1A Mod 8 and Mod 12 conforms exactly to the description given in OP 1064 for Computer Mk 1. In Computer Mk 1A Mods 13, 14, 15, and 16 the network is similar to that described in OP 1064, except that the quantity *R2m* is substituted for *R2* as an input to the ballistic computer (see fig. 6–4). The quantity *R2m* is equal to *R2* plus the initial velocity correction *jR2m*, indicated in the figure. This correction is additional to those described under the heading "Initial Velocity" on page 309 of OP 1064. Following is a description of this additional correction.

Correcting *Tf/R2*. When using *R2* as an input to the *Tf/R2* ballistic cam, as in Computer Mk 1, the output, *Tf/R2* contains an error due to the variation of the *I. V.* setting from the value of initial velocity for which the ballistic cams were designed. It should be noted that a partial correction for this variation has been incorporated in *R2*. The accuracy of the *Tf/R2* computation is increased by applying the supplementary *I. V.* correction, *jR2m*, to the *R2* input to the *Tf/R2* ballistic computer. An *I. V.* dial and and a knob are provided at the front of the computer for the purpose of introducing this supplementary *I. V.* correction.

The supplementary correction (*jR2m*) is obtained by means of a gear ratio in the shaft line from the front *I. V.* dial. The quantity *jR2m* is added to *R2* in differential *D*–91

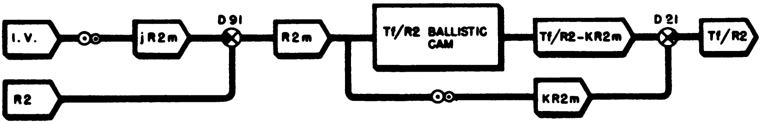


Figure 6–4.—Supplemental *I. V.* correction for *Tf/R2*.

to produce $R2m$, the altered advance range input to the $Tf/R2$ ballistic computer (see fig. 6–4). One branch of the $R2m$ shaft line drives the $Tf/R2$ cam; the other by-passes the cam and is multiplied by a constant $K$, through gearing to produce $KR2m$, which is the straight line approximation of $Tf/R2$. The output of the cam $(Tf/R2-KR2m)$ is added to $KR2m$, in differential $D$–21, to produce $Tf/R2$.

THE $Vf+Pe$ BALLISTIC COMPUTER. In Computer Mk 1A, Mod 13 only, with $Vf+Pe$ ballistic computer, follow-up is provided with a capacitor and microswitch arrangement similar to that just described for the $Tf$ ballistic computer follow-up. The purpose of this is to further reduce oscillations of the gun elevation order output. The only difference between the two arrangements is that the switch actuating cam of the $Vf+Pe$ follow-up is designed to cut in the 4-mfd capacitor immediately upon any movement from the synchronized position, rather than after approximately one-third revolution of the cam shaft.

### Computing Sight Deflection, *Ds*

The description contained under the heading Computing Sight Deflection in OP 1064 is applicable to Computer Mk 1A, except that where reference is made to 2550 *I. V.*, the design *I. V.* of the particular mod should be substituted.

## PARALLAX

The description under the heading "PARALLAX" in OP 1064 is applicable to Computer Mk 1A with the exceptions given below.

Computer Mk 1A Mod 15 does not compute parallax in elevation due to a horizontal base $(Pv)$. Instead, it computes another parallax quantity, parallax range. With the omission of the $Pv$ computation in Mod 15, a cosine output rack is not required in the parallax component solver and is therefore omitted.

### Parallax Range

The Computer Mk 1A Mod 15 computes parallax range. This is a factor in the computation of the parallax correction that must be applied to gun train order to correct gun train for the horizontal base between the reference point and the gun. Since the train parallax computer provides *Ph* for the directors, another mechanism is needed to compute *Ph* for the guns. Such a mechanism is located at each gun. However, the Computer Mk 1A aids the computation by supplying one factor, namely, parallax range, equal to sec $\frac{(E2+L)}{R2}$. Transmitted to the guns, this quantity is then multiplied by sin *B'gr* and the applicable constants to produce the required parallax correction.

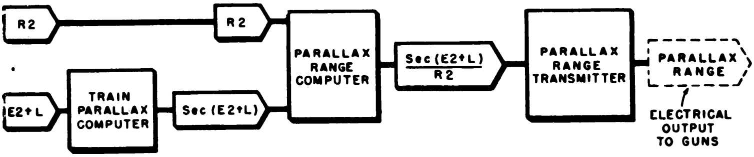


Figure 6–5.—Parallax range network.

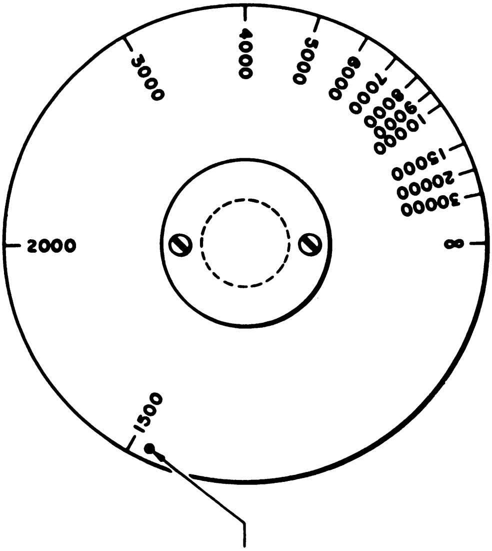


Figure 6–6.—Parallax range dial.

In computing parallax range, the train parallax computer supplies sec $(E2+L)$ which is multiplied by $1/R2$ in the parallax range computer (see fig. 6–5). The parallax range computer is a single-cam computing multiplier. The cam is positioned by advance range $(R2)$ and computes $1/R2$. The input rack is positioned by sec $(E2+L)$ supplied by the train parallax computer. The output of the parallax range computer is sec $\frac{(E2+L)}{R2}$.

Parallax range is transmitted to the guns by a single-speed transmitter. The transmitter dial is graduated in yards, from 1500 to infinity. The space between graduations varies inversely with advance range; that is, as the range increases the space between graduations decreases (see fig. 6–6). This dial is used for test purposes only, the infinity mark indicating electrical zero of the transmitter, and a white dot on the dial (see fig. 6–6) being used when adjusting the parallax range computer. The range graduations are used to test the accuracy of the instrument computations, $E2$ and $R2$ being set in the computer and the resulting value of parallax range being read on the dial.

## QUIZ

1. What was the purpose of altering the dials and gearing of the ship speed, target speed, rate of climb and wind speed inputs of the Computer Mk 1A?
2. How are the components of target motion taken in the Mk 1A computer?
3. What is the purpose of the target elevation ($E$) that is transmitted electrically by the potentiometer?
4. In what position must the control switch on the Mk 1A computer be to allow automatic bearing and elevation corrections by the director trainer and pointer?
5. What does the value set at the range time constant knob indicate?
6. How is the maximum sensitivity of the sensitivity mechanism obtained in the Mk 1A Computer?

7. In what type operation does the Mk 1A computer (rate control group) provide automatic correct values of *Sh*, *dH*, and *A*?
8. What two methods are available for starting the time motor of the Mk 1A computer when properly set up for standby condition?
9. What is the purpose of the two capacitors, 4 mfd and 1 mfd, connected in the *Tf* servo motor circuit?
10. What is the purpose of the halving gears installed in the output lines of the prediction multipliers?
11. By what two means is it possible for a Mk 1A computer operator to cause the range dials to match up when they are out of synchronism?

# CHAPTER 7

## RELATIVE-RATE ANTIAIRCRAFT SYSTEMS

### INTRODUCTION

Increased aircraft speeds in World War II made necessary the development of fire-control systems which could further reduce this time of solution of the problem of hitting aircraft. This step was vitally necessary for the control of machine guns, for which solution time is limited by the relatively short effective range of the weapons. A further requirement was that, inasmuch as an individual system is provided to control each mount, each fire-control system had to be limited in size and weight. On the other hand, the greatest danger to the ship was from incoming planes at close ranges, so many of the factors computed by such a fire-control system as the Mk 37 could be safely ignored. The result was the development of a family of lead-computing or relative-rate systems which differ from the Mk 37 fire-control system in that they measure rate of change of bearing and elevation directly as angular quantities, and measure these quantities simply by tracking the target. Although originally used for machine guns, systems of this type have been developed to control guns as large as 6-inch at close and intermediate ranges. The earliest and least complicated of these systems is the Gun Sight Mk 14. However, attention is now focused on more elaborate systems which operate basically on the same principles as the Gun Sight Mk 14.

Some relative-rate systems offset the fore-and-aft axis of the sight case by the amount of computed lead angle, so that the sight itself is alined with the gun-bore axis. These systems are known as DISTURBED-LINE-OF-SIGHT systems. Most lead-computing systems are of this type. Other systems, however, measure lead angles and transmit them to a computer which makes up the gun orders, while leaving the sight telescope, fixed in relation to the sight case, in the line of sight. These are UNDISTURBED-LINE-OF-SIGHT systems.

The purpose of this chapter is to help you understand the total operation of the Mk 63 and Mk 56 systems—the relationship between the component parts and the method used in each system to solve the fire-control problem. Once you have the overall picture of these two systems, the adjustment and maintenance procedures detailed in OP's will be easier to understand and follow.

## GENERAL DESCRIPTION OF GFCS MK 63

The Gun Fire-Control System Mk 63 is manually operated and is designed to control the fire of 40-mm and 3″/50 caliber guns against air targets at ranges from 800 to 7,000 yards. Range-rate limits on mod 11 installations are plus 350 knots and minus 800 knots. Targets may be tracked either optically or by radar. The radar antenna is carried on the gun mount. The system uses a DISTURBED-LINE-OF-SIGHT, meaning that while the sight housing and gun barrels are aimed at future target position, the optical line of sight and radar beam remain on the present target position.

The major units included in the system are:

1. Gun Sight Mk 15 or Mk 29.
2. Director pedestal.
3. Antenna mount.
4. Radar equipment.
5. Wind transmitter.
6. Target acquisition unit (TACU).
7. Train parallax corrector (if guns are displaced 12 yds. or more from the director).

### Operation

A crew of six is required for operation of the Mk 63 System. Topside personnel are the control officer, the director pointer, the director range setter, and the gun control talker.

The target acquisition unit (TACU) operator and the radar operator are stationed below decks.

A lead-computing sight Mk 15 or Mk 29, employing air-driven gyroscopic computing mechanisms, is mounted on a pedestal-type director. The director is swung manually by the director pointer in train and elevation. Tracking can be accomplished in two ways. If the target is visible, it is tracked by keeping the reflection of the target image centered on a fixed reticle in the optical telescope. This method is known as optical tracking. If the target is obscured, or, when night firing, the director pointer tracks a radar target spot which is introduced into the optical line of sight by a train and elevation scope in the gun sight. This method is called blind tracking. When the target is sighted optically, the director pointer slews the director to get on, using an auxiliary telescope. A caging switch on the left handle of the director is pressed during this operation to prevent the gyros from generating an undesirable lead angle and to prevent damage to the gyros.

As quickly as possible after the target is picked up in the auxiliary telescope, the pointer shifts to the tracking telescope of the gun sight and starts tracking smoothly, releasing the caging switch as the target is tracked. Corrective data from other units in the system (wind transmitter for wind corrections and radar for ranges and range rates) are transmitted to the director and applied as inputs to the gun sight automatically or by the range setter, who matches zero readers, thus sending these corrections into the gun sight. The corrections cause movement of the mirrors in the gun sight, changing the relative positions of the target image and reticle. The pointer, in maintaining the center of the reticle on the target, causes the director and the guns it controls to be offset from the line of sight and to point ahead of (lead) the target because of movement of the mirrors in the optical system caused by precession of the gyros. The lead angle compensates for the relative motion of the target and for the effects of gravity, wind, drift, *I. V.*, and spots, if any.

The lead angle is composed of two components: one in elevation, the other in train. The latter is corrected for horizontal parallax before being used at the gun in installations where this refinement is warranted. The amount the director is offset from the LOS in elevation and train is continuously sent to the gun during tracking in the form of signals which control drives at the gun.

### Improved Modifications

In later modifications of the Mk 63 system, the Mk 29 sight has replaced the Mk 15 sight because it provides for handling greater target speeds. Also the Mk 1 Mod 0 director pedestal has replaced the Mk 51 director in later installations. The Mk 1 Mod 0 director pedestal incorporates one important feature not installed on the Mk 51 director, a cross-roll gyro. When the computer "cross rolls" or swings about the line of fire because of deck inclination, the elevation and train gyros tend to interchange functions. This interchange, however, is retarded somewhat by gyro damping. To compensate for errors caused by the damping, the cross-roll gyro measures cross roll directly and modifies the output of the sight accordingly by means of cross-roll torque motors on the gyro output shafts in the Mk 29 sight.

### Radar Equipment

The earliest Mk 63 systems used Radar Equipment Mk 28, while all others use the Mk 34. The Mk 34 radar sends to the gun sight values of range and range rate which are used in computing lead angles both in full and in partial radar control. In addition, the radar provides target-position signals for blind tracking. In blind tracking, as in optical tracking, the director is positioned manually, but the radar equipment aids the director pointer by locating an obscured target initially by means of the TACU unit, and by providing a target indication in the sight as a spot in the scope which can then be tracked once the radar beam has been placed on the target.

As shown in figures 7–1 and 7–3, the radar antenna is mounted in a gimbal above the gun trunnions on the mount. Sufficient angular displacement permits the antenna to be offset from the bore axis in accordance with the lead angles generated by the gun sight. The limits are about 30° in any direction. This feature is necessitated by the fact that the antenna is mounted on the gun, which, of course, is laid for a predicted target position by the lead angles generated by the sight. The radar beam must remain at present target position. Signals positioning the guns are sent from the director to the guns. The same signals are sent to the radar antenna drive, but in the opposite direction, to keep the antenna on the line of sight.

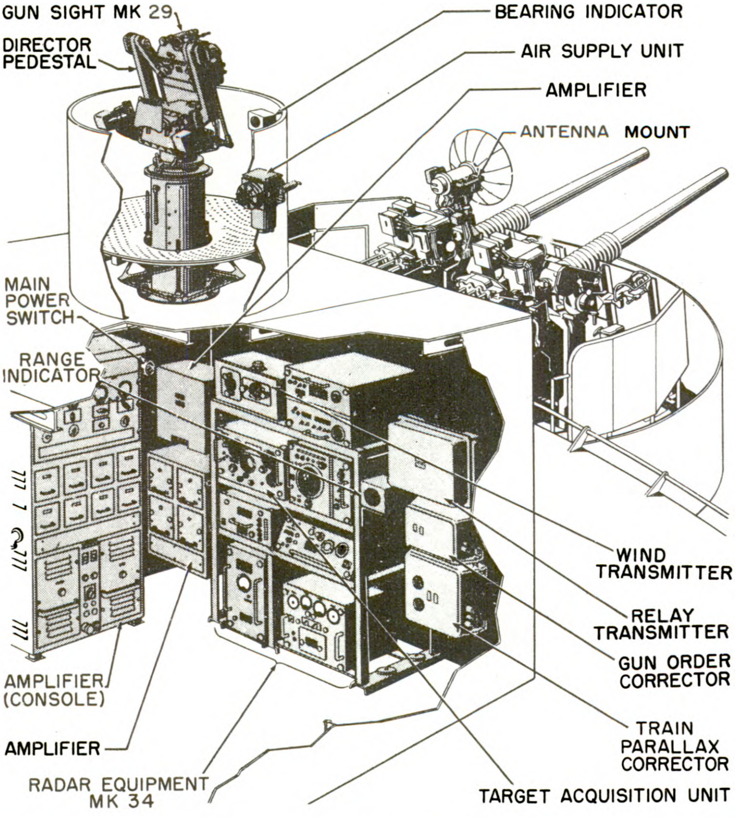


**Figure 7–1.—Major units topside and below decks, gun fire-control system Mk 63.**

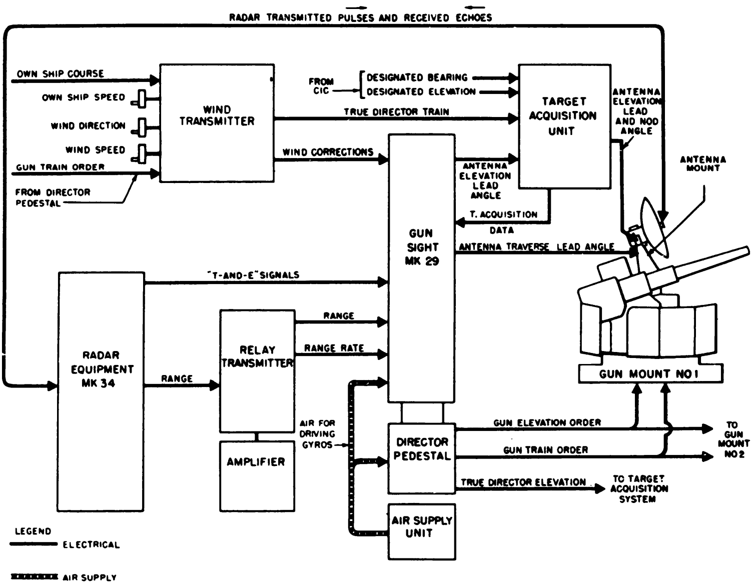


Figure 7–2.—GFCS Mk 63, simplified flow diagram.

The antenna is a parabolic reflector with a feed line known as a nutator projecting from its center. A narrow conical beam of energy is radiated. By action of the nutator this beam is deflected from the axis of the reflector and is rotated, thus providing a cone-shaped area of scan.

## Target Acquisition

The target acquisition unit (TACU), which is a part of the Mk 34 radar, is located in the radar room. When visibility is poor, or when numerous targets are at the same approximate location, the TACU aids the director operator in acquiring the designated target. The TACU operator receives target information from an outside station, such as a search radar or a lookout, and can control the position of the TACU spot in the director pointer's train and elevation (T & E) scope to indicate the direction of movement necessary to point toward the designated target. If the target

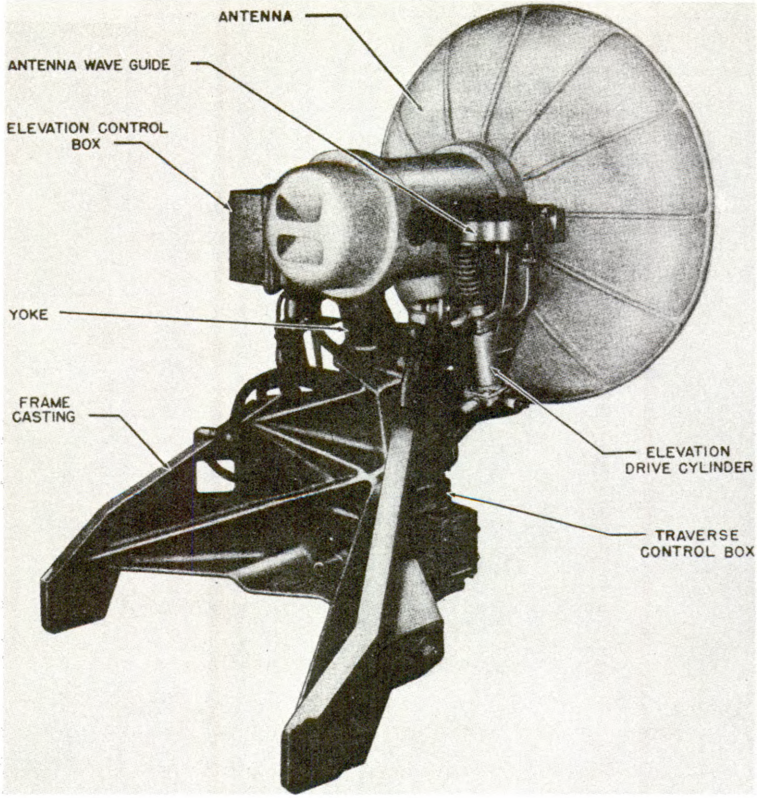
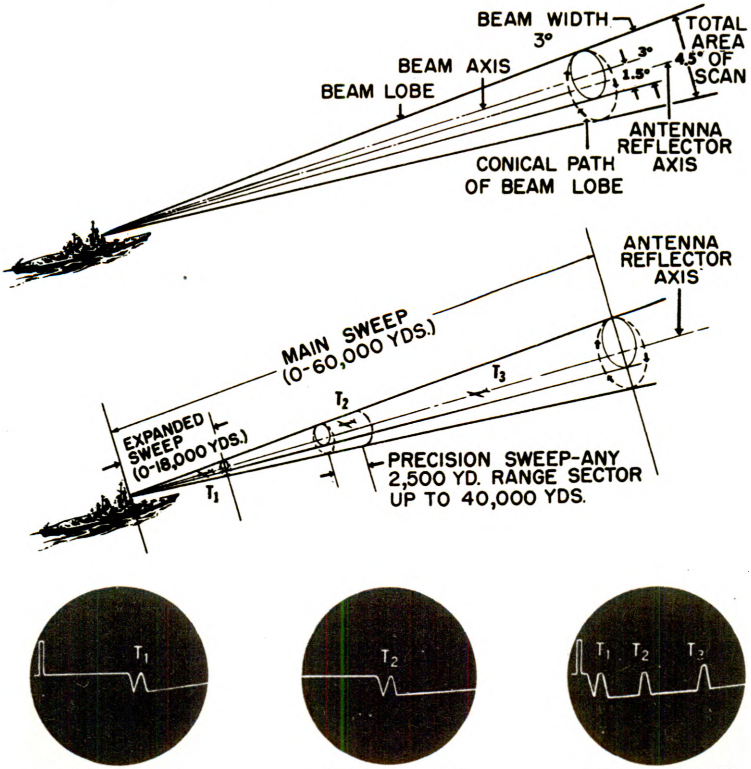


**Figure 7–3.—Antenna mount (with antenna assembly), GFCS Mk 63.**

fails to appear in the TACU scope, the TACU operator can cause the antenna to nod in elevation at an angle of either ±15° or ±5° by a selector switch. Search in bearing can also be accomplished by throwing a switch which causes the spot to move back and forth across the T & E-scope. If the director pointer follows the spot, the TACU operator is enabled to scan a small bearing sector about the designated bearing. Close cooperation between TACU operator and director pointer is necessary to locate and get on a designated target. It should be noted that the spot used to coach the director pointer on the target is controlled by the TACU operator and is not the spot which appears on the pointer's scope once the target lies within the radar beam. Once the target has been picked up by radar, the TACU operator can determine range, bearing, and elevation data from a scope on the TACU.

### Ranging

The radar operator, also stationed in the radar room, has two units which provide visual information about the target, namely, the control indicator and the range unit. On the control indicator, echoes from targets within the radar



RANGE UNIT EXPANDED SWEEP

RANGE UNIT PRECISION SWEEP

RANGE UNIT MAIN SWEEP

Figure 7—4.—Beam and sweep characteristics.

beam appear as pips along the horizontal sweep. The range-measuring indication is a sharp drop or step in the sweep line. When the step is set adjacent to the leading edge of a pip, a counter on the range unit shows the range in yards. By throwing a selector switch, a choice of three sweeps is possible, as shown in figure 7–4. Main sweep, used for locating distant surface and air targets, shows all targets within the beam from 0 to 60,000 yards. The range crank moves the step to a maximum of 40,000 yards, beyond which target range must be estimated. Expanded sweep is accurate and is sufficient for most air targets, since it includes the firing range. It shows all targets from 0 to 18,000 yards, the range step again moving as the range crank is turned. Precision sweep, used for very accurate range measurement and tracking, covers any desired 2,500-yard sector of the entire measurable range (40,000 yards). In this case the step remains in the center of the sweep and the pips move along the trace as the crank is turned.

A small portion of the sweep—about 300 yards in range—is known as the range gate. The target is gated by turning the range crank on the range unit until the leading edge of the pip is adjacent to the sharp point at the base of the step. A drop in amplitude of all pips and grass along the sweep indicates that a target has been gated. Effective tracking can be accomplished only on gated targets, since no others will show upon the director pointer's T&E-scope. Targets may be tracked (kept gated) either manually by moving the range crank or by an aided tracking unit which causes the range step to move along automatically at a uniform rate. For fast-moving targets, the latter will give smoother tracking.

## Operation in Train and Elevation

The scope on the control unit duplicates the image on the director pointer's T&E-scope. This train and elevation indicator permits the radar operator to work more closely with the director pointer.

The gun sight contains a T&E-scope for the information

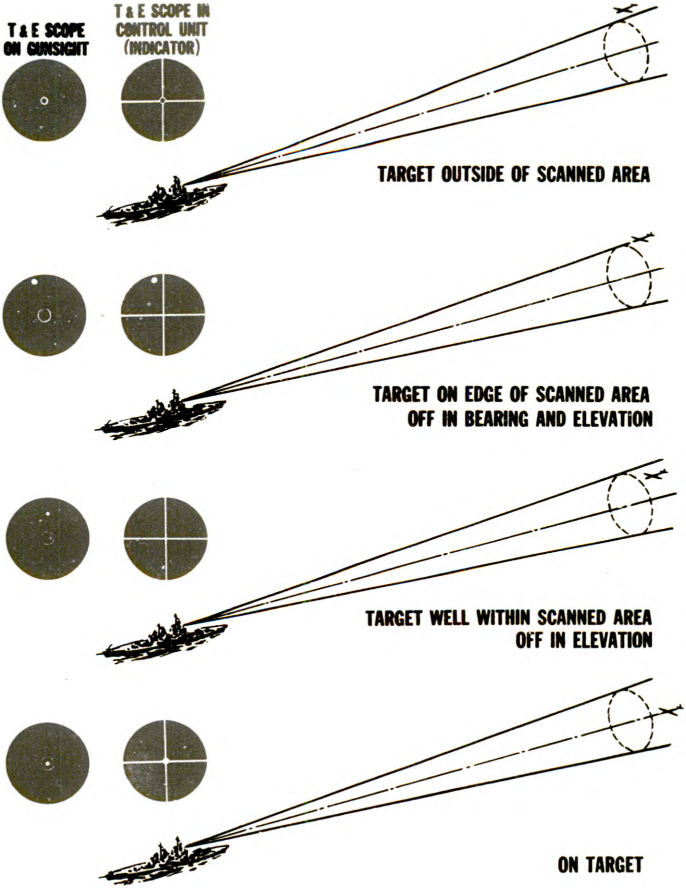

T & E SCOPE ON GUNSIGHT
T & E SCOPE IN CONTROL UNIT (INDICATOR)
TARGET OUTSIDE OF SCANNED AREA
TARGET ON EDGE OF SCANNED AREA OFF IN BEARING AND ELEVATION
TARGET WELL WITHIN SCANNED AREA OFF IN ELEVATION
ON TARGET

**Figure 7–5.—Target indications on T&E-scope.**

of the director pointer. Once the target is gated, the spot on the T&E-scope enables him to correct errors in the pointing, as shown in figure 7–5. Since the radar beam is being rotated, a target which is gated but not exactly on the center of the antenna axis will return a signal of different strength for each position of the radar beam. Such a target will give an image (spot) displaced from the center of the T&E-scope, and the direction of the spot from the center indicates the direction in which the antenna must be moved to center the spot. When the target is exactly on the axis of the antenna, the spot is in the center of a circular reticle. Keeping the spot so centered tracks the target.

The T&E-scopes give indications of signal strength as well as pointing error. A strong echo appears as a bright spot, weaker echos as small rings increasing in size as the echo becomes weaker. When the echo is no longer present, a concentric "no signal" circle settles inside the circular reticle at the center of the scope.

## GENERAL DESCRIPTION OF GFCS MK 56

Gun Fire-Control System Mk 56, illustrated in figure 7–6, is an intermediate-range antiaircraft fire-control system. Designed for use against high-speed subsonic aircraft targets, it provides gun train, gun elevation, and fuze orders for 3-, 5-, and 6-inch guns. It also may be used against surface targets.

Where a ship has two batteries (of different calibers) capable of AA fire, the system can produce different gun orders for both batteries simultaneously, thus permitting both to fire on the same target. This variation is known as a dual-ballistic system.

The system incorporates:

1. Automatic radar tracking in bearing, elevation, and range, as accurate as the best optical tracking.
2. Remote control of the entire system from the control room below decks, which provides for rapid radar acquisition of obscured targets and for blind firing. Solution time of this system is relatively short (2 seconds), so firing can begin early in tracking.

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room.

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console by matching designating dials.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead

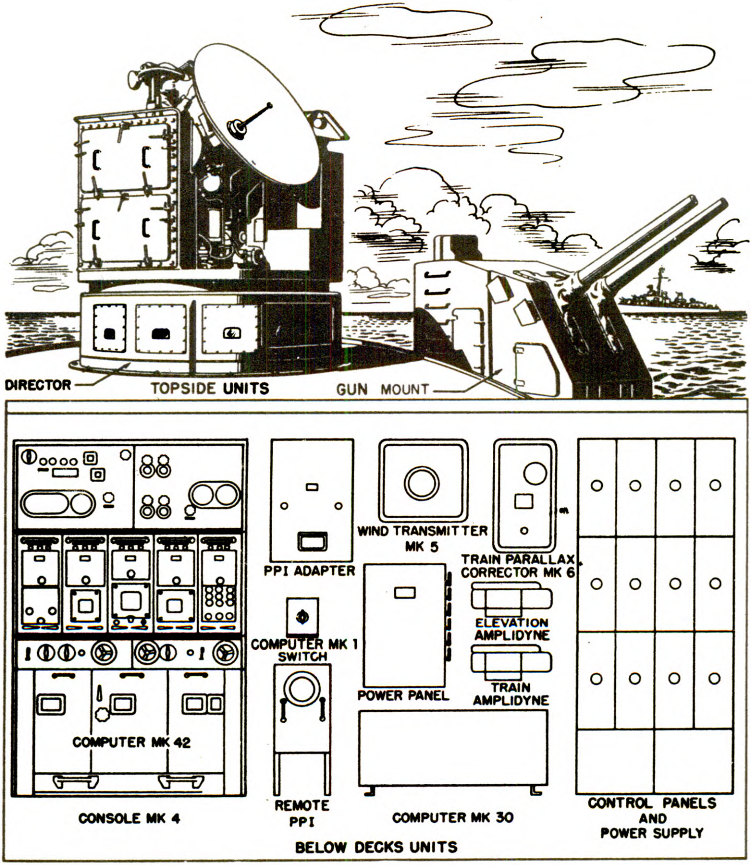


Figure 7–6.—Components of gun fire-control system Mk 56.

angles is based on director angular rates of motion in stabilized coordinates.

The discussion to follow presents first a general treatment of the fire-control problem as solved by the system, then a detailed description of system components and operational controls.

## Target Positioning by the Mk 56 System

Figure 7–7 shows some of the space relations used in the Mk 56 system. The angular velocity of the LOS can be resolved into angular rates in two planes, elevation and traverse, *dE* and *dBs*. In the GFCS Mk 56, these rates are measured by the rate gyro, which is stabilized and hence measures the rates in the true elevation and the true traverse plane.

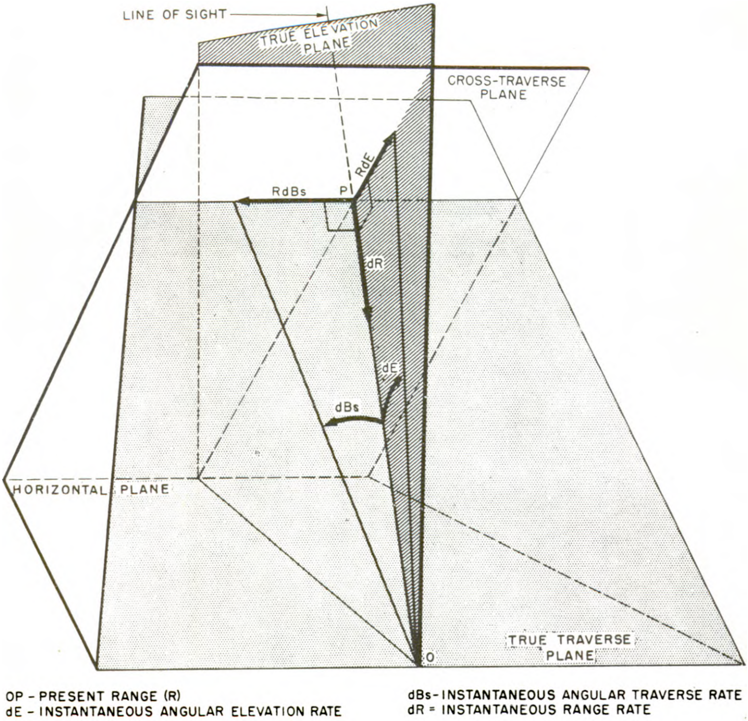


**Figure 7–7.—Linear rates of target motion.**

The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane, and contains *RdE* and *RdBs.* Since the target is not moving entirely in the cross-traverse plane, the range changes at the rate *dR*, measured along the line of sight. *RdE*, *RdBs*, and *dR*, then, are the three basic linear rates of target motion.

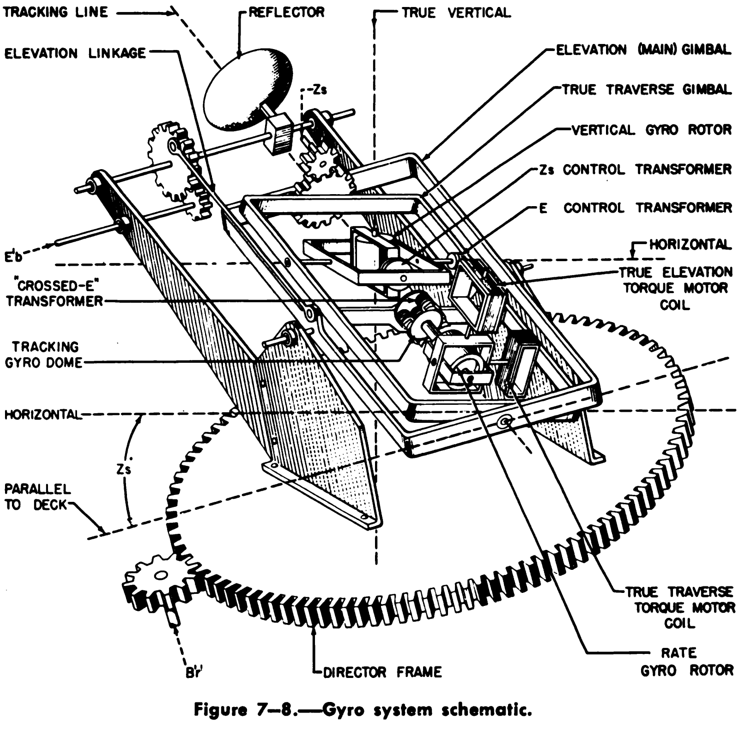


**Figure 7–8.—Gyro system schematic.**

The first step in the solution of the problem by the Mk 56 is the determination of target position. Target bearing and elevation are measured by the director. As the target is tracked, director train, *B′r′* and director elevation *E′b* are measured and transmitted by the synchros; electrical signals representing these angles are transmitted continuously to the computer. Target range (*R*) is measured by gating the target pip on the radar indicator. The range signal is transmitted automatically from the radar equipment to the computer.

Tracking the target is accomplished either optically or by radar. For optical tracking, a hand-grip type of tracking control unit and a telescope are provided on the director. Rotation of the hand grips generates electrical signals that control the director power drives in elevation and train.

In automatic radar tracking, the tracking signals originate in the automatic tracking circuits of the radar equipment. These error signals vary with deviation of the target from the center of the radar beam when in conical scan. Automatic tracking is accurate within one-half mil.

The director line of sight is stabilized by a gyro unit, located in a compartment at the rear of the director. The unit, shown schematically in figure 7–8, consists of a vertical gyro and a rate gyro. The gyroscope unit is mounted on pivots in the gyro compartment. The elevation linkage attached to the antenna elevating gear is used to tilt the gyro main (elevation) gimbal so as to maintain the gyro gimbal axes parallel to the line of sight.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane, as shown in figure 7–7. The vertical gyro, as shown in figure 7–9, also measures *E*, true elevation of the director line of

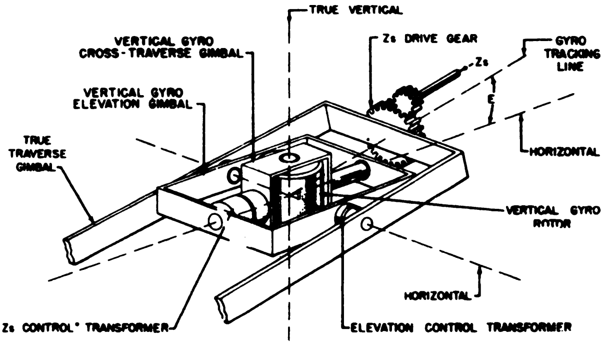


Figure 7–9.—Vertical gyro.

sight above the horizontal, and $Zs$, cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck. However, cross traverse is measured in the cross-traverse plane, which is perpendicular to the line of sight, and therefore differs from crosslevel. The values of $E$ and $Zs$ are picked off by elevation and cross-traverse control transformers and are transmitted to the computer, where they are applied in calculating ballistic corrections and gun orders. $Zs$ also goes to the cross-traverse drive gear of the rate gyro.

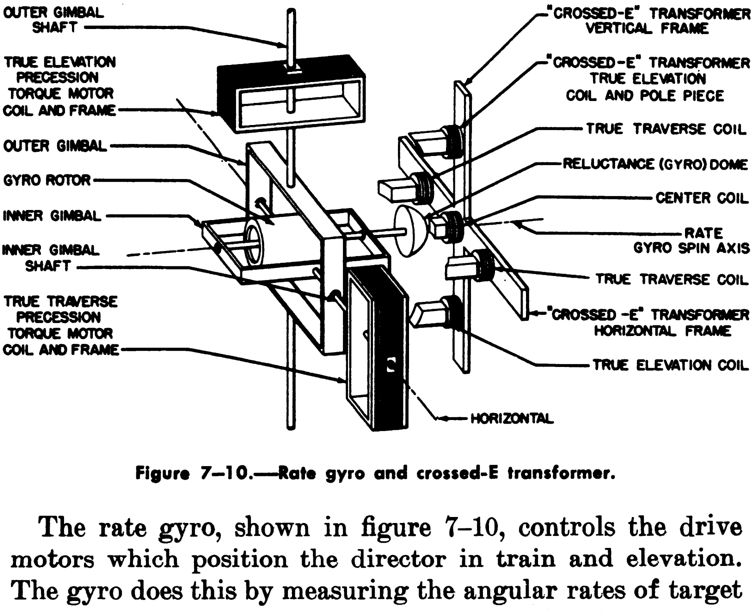

OUTER GIMBAL SHAFT
TRUE ELEVATION PRECESSION TORQUE MOTOR COIL AND FRAME
OUTER GIMBAL
GYRO ROTOR
INNER GIMBAL
INNER GIMBAL SHAFT
TRUE TRAVERSE PRECESSION TORQUE MOTOR COIL AND FRAME
"CROSSED-E" TRANSFORMER VERTICAL FRAME
"CROSSED-E" TRANSFORMER TRUE ELEVATION COIL AND POLE PIECE
TRUE TRAVERSE COIL
RELUCTANCE (GYRO) DOME
CENTER COIL
RATE GYRO SPIN AXIS
TRUE TRAVERSE COIL
"CROSSED-E" TRANSFORMER HORIZONTAL FRAME
TRUE ELEVATION COIL
HORIZONTAL

**Figure 7–10.—Rate gyro and crossed-E transformer.**

The rate gyro, shown in figure 7–10, controls the drive motors which position the director in train and elevation. The gyro does this by measuring the angular rates of target motion in the form of electrical tracking signals and combining these signals with the stabilizing signals $E$ and $Zs$ from the vertical gyro. The algebraic sum of these signals is obtained in a set of pick-off coils called a crossed-E transformer and shown in figure 7–10. The crossed-E transformer is composed of five coils arranged to form a cross with axes at right angles. The center coil is energized by 100 volts, alternating current. This voltage induces voltages in the other coils. Supported by the vertical frame, coils are kept oriented in the vertical plane through the tracking line, as shown in figure 7–8, and are connected in phase opposition. The other two coils are oriented in the true traverse plane. Carried on the rate gyro shaft is the reluctance dome.

When the rate gyro is positioned with its center over the center coil of the crossed-E transformer, the air space between the dome and the transformer coils is the same, and the voltages induced in the coils on opposite sides of the transformer are the same, but opposite in phase. Consequently, the output is zero. When the dome moves off center, the voltages in opposite coils become unequal and error signals in elevation and traverse are generated. This operation is similar to that of the umbrella and magnet in the stable vertical.

The error signals in elevation and traverse form part of the input to the director drive motors. In this manner, the director is driven to stay on the target, even though the ship is rolling and pitching.

### Measuring Rates of Target Motion

If the director remains on target continuously, the angular rates of director motion are the same as the angular rates of relative target motion. Therefore, the train and elevation tracking signals are transmitted to the computer as rates of target motion, *dE* in elevation and *dBs* in traverse.

In obtaining these rates of target motion, the property of gyroscopic stability is used. As the director tracks the target, the rate gyro tends to lag behind, causing the radar antenna and the optical telescopes to lag. The need for correction becomes obvious to an optical tracker, who gets back on the target by handwheel motion, thus correcting the error. With automatic radar tracking, error signals are introduced electronically. In either type of tracking, the error signals generated go to the elevation and traverse torque motors shown in figure 7–10. The gyro is precessed to follow the target, but this is only the first step in repositioning the director. In addition, the reluctance dome carried by the gyro is moved off center when the gyro is precessed. Voltages are induced in the coils of the crossed-E transformer, and these voltages are used to drive the director in train and the antenna in elevation until the director line of sight is back on the target.

The crossed-E transformer receives error signals due to tracking rates and also stabilizing signals produced when the antenna moves off the target because of deck inclination. The two are continuously combined, and the director is driven to correct for both effects.

Also required in computing lead angles is range rate, *dR*, which is obtained from a tachometer attached to the shaft of the range servo motor. The tachometer is a small generator whose output voltage varies with speed of rotation. The output voltage is therefore a measure of the rate at which the range motor is rotating, in other words the rate of change of present range.

From the three rates of target motion, *dE*, *dBs*, and *dR*, the computer calculates lead angles in true traverse and true elevation to account for movement of the target during time of flight.

### Ballistic Corrections

The computer consists of the following units: ballistic computer, wind transmitter, parallax corrector, and gun order converter, together with associated amplifiers. Computations are performed by a chain of electrical and mechanical networks distributed among these units. Because of physical distribution and intermingling of circuits, any of these units or all of them together is considered as the computer.

Based on the inputs of present target position and rates of target motion, the computer calculates superelevation and drift. To correct for the effects of wind, the computer receives electrical values of own-ship course from the ship gyro compass and manually introduced values of true wind speed, true wind direction, and own ship's speed. Corrections are made for the effects of apparent wind upon projectile travel in elevation, traverse, and range.

The ballistic corrections in the Mk 56 system are computed in terms of rates. In accomplishing this the angular rates *dE* and *dBs* received from the director are first multiplied by *R* to give linear rates *RdE* and *RdBs*. Then corrections to the linear rates, *RdE*, *RdBs*, and *dR* are worked out for superelevation, wind, etc. For example, *RdBsf* is the correction to *RdBs* for drift, *RdBsw* for wind. The final corrected rates, shown in figure 7–11, become *RdBstfw*, *RdEtfpw*, and *dRtfw*. The *t* indicates relative target motion and the *p* a correction for vertical parallax.

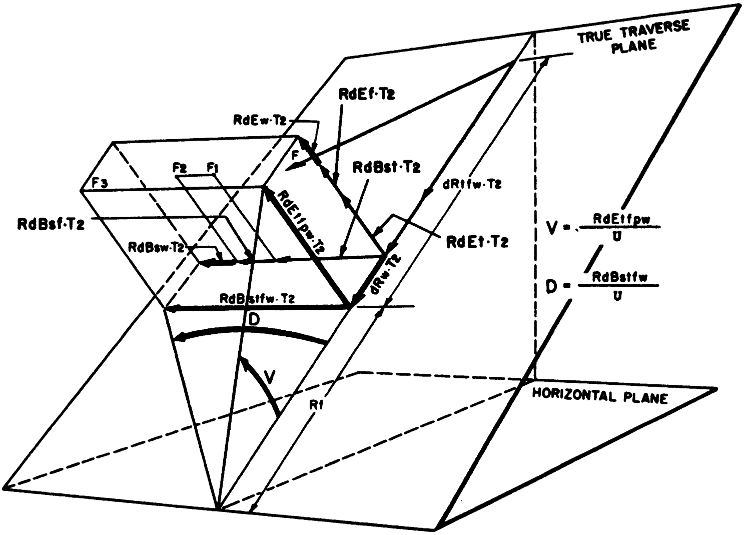


**Figure 7–11.—Target-motion lead angles.**

Unlike other systems, the Mk 56 does not multiply the applicable linear rates by time of flight to obtain lead angles *V* and *D*. Instead, the rates are divided by average shell velocity *U*, where $U = \frac{R2}{Tf}$. Basing the solution on *U*, the average velocity, gives more accurate predictions. The most accurate solution is obtained at a medium range, with accuracy decreasing to give maximum error at either a short range or maximum range. However, the maximum errors are so small they do not affect the accuracy of gunfire appreciably. With a chronograph operating in conjunction with the radar, very accurate values of *U* are obtained.

When *U* is not measured by chronograph, the computer must receive a manual input of initial velocity to correct for variations in projectile velocity caused by gun erosion, powder temperature, and atmospheric density. When the chronograph is used, the input is actual average velocity of the projectile in flight.

A manual input of dead time must also be introduced into the computer to compensate for the effect of gun-crew loading time upon fuze time order.

The lead angles *V* and *D*, shown in figure 7–11, are in the true elevation and true traverse planes. Since present target position is measured in deck coordinates, the lead angles must be converted into their equivalent angles in deck coordinates. This conversion is performed in the Mk 30 computer by a graphic device called the axis converter. The converter is a small dummy-gun arrangement which reproduces the actual conditions of the problem. The stabilized lead angles are set into the converter, and the correct values of lead angles in deck coordinates are continuously picked off and used in making up gun orders.

Parallax correction is accomplished in three parts: (1) an elevation correction to account for the vertical displacement of the gun mount from the director, (2) a correction to director train to correct for the fore-and-aft displacement of the director from the ship's reference point, (3) unit parallax correction (100-yard base length), which is transmitted to the gun mount, where a correction is made to gun order for displacement of gun mount from reference point.

## Composition of Gun Orders

With the lead angles *V* and *D* in true coordinates converted to the deck-plane coordinates as $V'd$ and $D'd$, they can be added to $E'b$ and $B'r'$. Gun elevation order $E'g=E'b+V'd$ and gun train order, $B'gr=B'r'+D'd$. These values are

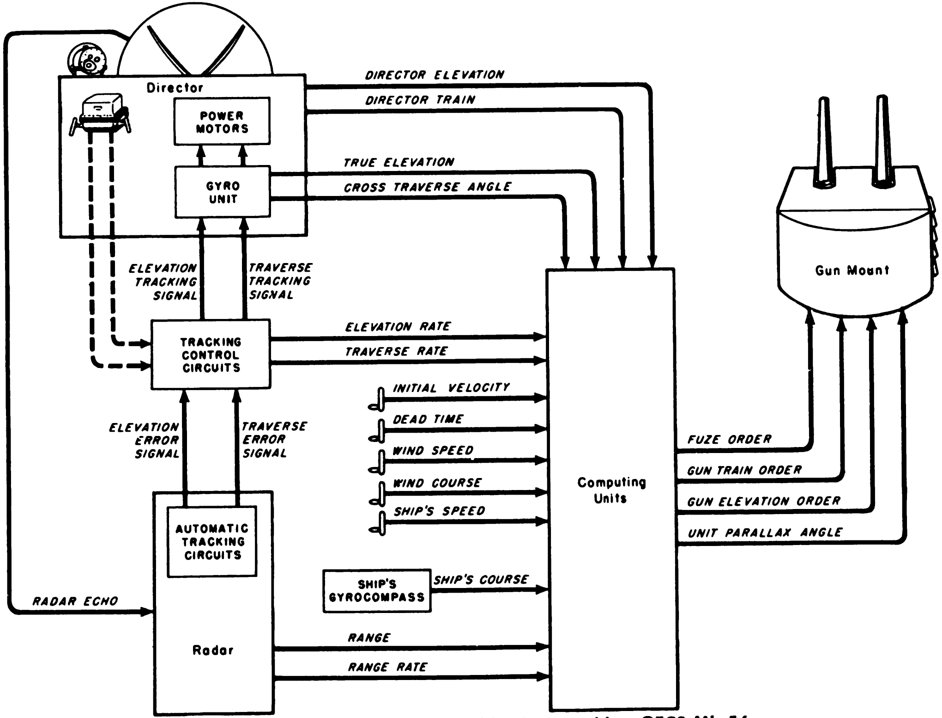


Figure 7–12.—Flow diagram of basic quantities, GFCS Mk 56.

transmitted to the guns, where a final correction for horizontal gun parallax is introduced into gun train order.

The fuze setting order (*F*) for mechanical time fuzes is computed in the Mk 42 computer.

## Summary of System Operation

Figure 7–12 shows the flow of basic quantities in the system when using automatic radar tracking, which is the usual method of operation. The radar equipment in the radar room receives target echoes from the antenna and transmits traverse and elevation error signals to the gyro unit as tracking signals and to the computer as rates of target motion. By resetting the control switches, signals from the optical tracking control unit in the director may be selected in place of radar error signals. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

In the gyro unit, tracking signals are added to stabilizing signals. The resultant signals control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course from the ship gyro compass is introduced to the computer electrically, while true wind speed, true wind direction, own ship's speed, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections, and makes up and transmits gun elevation order, gun train order, fuze time order, and unit parallax correction to the guns. Within two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.

## System Components

The components of a single-ballistic system of GFCS Mk 56 (figs. 7–6 and 7–12) are:

1. Gun Director Mk 56.

2. Radar Equipment Mk 35.
3. Console Mk 4.
4. Computer Mk 42 (ballistic computer).
5. Computer Mk 30 (gun-order converter).
6. Wind Transmitter Mk 5.
7. Train Parallax Corrector Mk 6.
8. Chronograph.
9. Bearing Indicator Mk 10.
10. Selector Switch Mk 13.
11. Control Panel Mk 23.
12. Control Panels Mk 27 and 28.
13. Train and elevation amplidyne generators.
14. Motor generator set.

In addition to these units, a dual-ballistics system requires for computing gun orders for the secondary ballistics:

15. Computer Mk 42.
16. Computer Mk 30.
17. Control Panel Mk 57.
18. Ballistics selector switch.
19. Secondary ballistics fuze control unit.

## The Components

1. Gun Director Mk 56 (fig. 7–13) is located above decks, in a position affording maximum visibility. Its primary function is to supply the computer with continuous present target position and rates of target motion.

The main body of the director is a shell of steel plate. A two-man director-operating crew is stationed in the left section, called the cockpit, with the control officer behind the pointer. In the cockpit are the tracking controls and various dials and switches used to operate the system. The right section consists of four watertight compartments which house the gyro unit and various above-deck units of Radar Equipment Mk 35. Mounted on the main body are the slewing sight, telescope, tracking control unit, and radar antenna.

The slewing sight consists of a pedestal with an elevating crossarm on which a binocular is mounted. Rotation of the pedestal about its vertical axis generates an electrical signal that positions the director in train. Rotation of the crossarm about a horizontal axis generates an electrical signal that positions the director in elevation. Slewing sight operation is controlled by a two-position switch at the pedestal base. With the switch in LOCK, the slewing sight will follow the director; in SLEW, the director will follow the slewing sight.

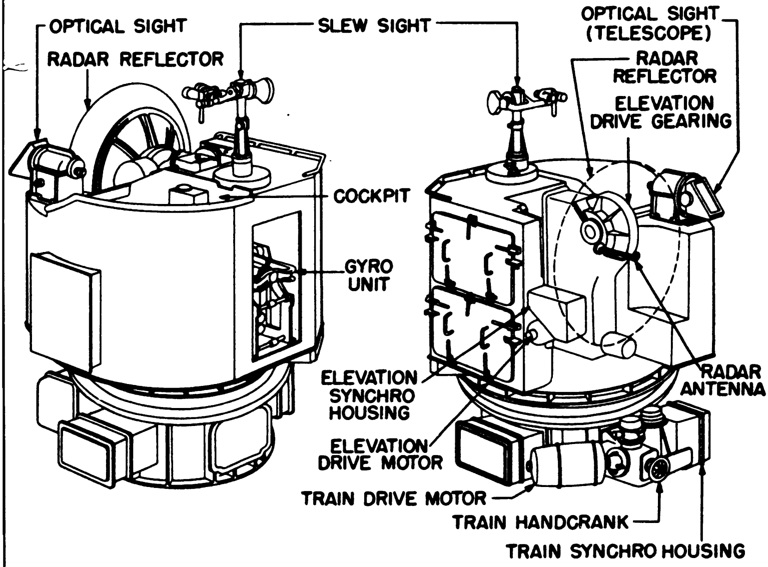


Figure 7–13.—Gun director Mk 56.

The pointer's tracking control unit is used for moving the director when tracking visible targets. This unit rotates about a vertical axis. The handgrips rotate about a horizontal shaft. Rotation about either axis generates an electrical signal that controls the director power motors.

The radar antenna assembly consists of a parabolic reflector, a nutating antenna feeder, and a scanning mechanism. The entire assembly, mounted on trunnions and connected to the director elevation gearing, elevates with the line of sight.

The antenna forms a beam of set width. The scanning mechanism nutates the beam in either conical or spiral scan.

In conical scan, the beam nutates through a cone of set diameter. In spiral scan, the beam nutates in a spiral pattern, providing a coverage in bearing and elevation.

The director is power-driven in train and elevation by d. c. drive motors controlled by below-decks amplidyne generators. Movement in train is unlimited, because all electrical connections to the director are through a slip-ring assembly located at the base of the director. Movement of the director in elevation is limited by mechanical stops. Electrical limit switches cut out power to the drive motors before the mechanical limit stops are reached.

The director is provided with locks for securing in train and elevation when the director is not in use. Securing locks incorporate a protective microswitch that cuts out power to the amplidyne generators when either lock is in the secured position.

A train handwheel and an elevation handknob are provided so that the director may be moved for securing purposes when the power motors are off.

For transmitting values of train and elevation, the director is provided with synchro transmitters connected to the train and elevation drive-gear systems.

2. **Radar** Equipment **Mk** 35 supplies: (a) the computing units with continuous values of target range and range rate for both optical and radar tracking; and (b) the director with signals for tracking obscured targets. Once on target, the system will track automatically when radar control is being used.

Components of Radar Equipment Mk 35 located above decks are the antenna, scanning mechanism and motor, transmitter and receiver. The radar indicators, range controls, adjustment controls, and automatic tracking circuits are located below decks on Console Mk 4.

3. Console Mk 4, figure 7–6, is the below-decks operational center. On it are the knobs, dials, and indicators necessary for below-decks operation of the system. While various phases of the computations are performed in separate computing units, inputs and power to these units are controlled from the console.

The console consists of four main sections: a dial section at the top, the radar section, the operational section, and Computer Mk 42 at the bottom. Bearing Indicator Mk 10 is mounted on the right side of the console.

On the face of the dial sections are knobs and dials for hand inputs to computing units; dials indicating range, elevation, and bearing; tracking-control indicating lamps; and a switch controlling computer operation.

The radar section consists of five panels containing the A/R-indicator, E-indicator, and B-indicator and switches for controlling radar operation.

The operational section contains the handknobs, slew levers, and switches for controlling the director in train and elevation, and for controlling range and antenna scan from the console.

4. Computer Mk 42, figure 7–14, is the ballistic computer. Its primary function is to compute projectile time of flight, superelevation, drift, range rate, and fuze order.

Dials indicate *I. V.* setting, true elevation of the director, range input to the ballistic computer, range rate as computed

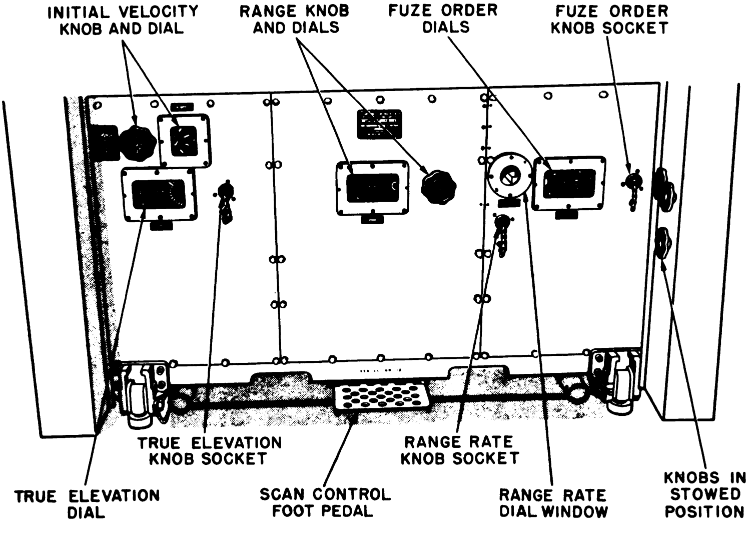


Figure 7–14.—Computer Mk 42.

by the ballistic computer, and fuze order being transmitted to the guns. Knobs are provided for setting these values manually when performing tests; however, for normal operation, the true-elevation, range-rate, and fuze-order knobs are removed from their sockets and stowed as shown in figure 7–14, and the range knob is disengaged. Only the initial velocity (*I. V.*) knob remains engaged.

The pedal below the center panel of the ballistic computer controls the type of antenna scan.

5. Computer Mk 30 is called the gun-order converter. Its basic function is to convert the rates of target motion in true coordinates into lead angles in deck coordinates, and combine them with director train and elevation to produce gun train and elevation orders.

Four dials indicate director elevation, director train corrected for parallax, gun train order, and gun elevation order. The input value of the cross-traverse angle is visible through a window.

6. Wind transmitter Mk 5 computes corrections to compensate for the effect of wind on projectile flight, and transmits them to the gun-order converter for inclusion in the solution of the problem. Electrical inputs of wind direction, wind speed, and ship speed are received from the console. A dial on the face of the wind transmitter indicates the direction from which apparent wind is blowing.

7. Train parallax corrector Mk 6 computes a correction for the displacement of the gun mount from the director along the ship fore-and-aft axis. It receives values of range, elevation, and director train. The outputs are: (a) director train corrected to the ship reference point which is transmitted to the gun order converter; (b) unit parallax correction, which is transmitted to the gun for correcting the value of gun train order. A dial indicates the unit parallax correction.

8. The chronograph measures the average velocity of the projectile, so that *I. V.* may be determined accurately.

9. Bearing indicator Mk 10 indicates director bearing (both relative and true) to the below-decks operating crew.

10. Selector Switch Mk 13, also called the Computer Mk 1A switch, is installed only on ships where GFCS Mk 56 is to be connected with Computer Mk 1A for surface fire. In the Computer Mk 1A position, the switch allows values of director train and range to be transmitted to Computer Mk 1A.

## Dual-Ballistics Units

A dual-ballistics system tracks one target but computes two sets of gun orders for guns of different ballistics. For example, in a typical light-cruiser installation, GFCS Mk 56 computes gun orders for 3″/50 and 6″/47 caliber guns.

The dual-ballistics system requires a second Computer Mk 42 for the secondary ballistics, using the same inputs as the primary ballistics computer, and a Computer Mk 30 which computes gun train order and gun elevation order for the secondary ballistics.

The ballistics selector switch controls power to the secondary ballistics computing units. It has two positions: PRIMARY and BOTH. The secondary units are energized when this switch is in BOTH.

The secondary ballistics fuze control unit controls fuze orders for the secondary ballistics.

## Control Officer's Station

The control officer has available the following operational controls:

1. Telephone-selector switch. This selects the telephone circuit or circuits he wishes to use. To speak directly to the radar operator or gun captain, he turns this switch to LOCAL. To parallel the circuits, he turns it to BOTH. Normally he leaves it on AIR DEFENSE.

2. Slewing sight and slew switch. This is used to slew the director to a visible target. Before the control officer can move the director by means of the slewing sight, he must position the slew switch to SLEW. With the slew switch on LOCK, control of the director reverts to another unit and the slewing sight will follow the director line of sight in train

and elevation. The slewing hand grip contains a press-to-talk button equivalent to the mouthpiece button of the control officer's sound-powered telephone.

3. Radar-optical switch. This switch takes precedence next after the slew switch. When the slew switch is on LOCK, the radar-optical switch can select either the director operator's tracking control unit (switch on OPTICAL) or the radar tracking circuits and remote director controls on the console (switch on RADAR).

4. Cockpit dial unit. This is used in positioning the director on the bearing and elevation of a designated target.

5. Stand-by range input unit. If the radar fails, the control officer can introduce values of estimated target range in increments of 1,000 yards. Normally, however, radar range is selected.

6. Angle-spot transmitter. This device has two dials, each graduated in mils. The upper is the elevation-spot dial and the lower is the deflection-spot dial.

7. Cease-firing contact maker. This is for communicating CEASE FIRING order to the gun crew.

### Director Operator's Station

1. Telescope Mk 60. The director operator tracks a visible target by keeping the crosshairs of the telescope reticle on the target.

2. The tracking control unit is operated to position the director when tracking a target optically. The slew switch must be in LOCK and the radar-optical switch in OPTICAL.

Since tracking signals are used in the computer as the rates of target motion, smooth tracking is of primary importance to the computation of accurate gun orders. To facilitate smooth tracking, an aided-tracking key is provided in the left-hand grip. When the key is closed, the tracking signals are fed through an aided-tracking circuit. The circuit is designed so that, for an instant after the tracking signals are changed (as the crosshairs drift off target), the director moves at higher rates than those called for by the new rates. The result is that the line of sight "hops" closer to the target and then settles down to the new rates. The director operator holds the aided-tracking key closed whenever he tracks a target.

A firing key with a safety lock is inset in the right-hand grip of the tracking control unit. To close the firing key, the director operator must first release this safety lock by pressing the lever to the left.

3. Open sight. An aid for getting on target.

4. The "press-to-talk" pedal is equivalent to the mouthpiece button used by the director operator. It permits the director operator to talk on his phone circuit while both hands are occupied with the tracking control unit.

5. The amplidyne power switch controls power to the amplidyne generators which supply the director drive motors. The amplidynes will not start before the gyro READY lamp lights, or the securing locks are off.

6. The cockpit illumination switch controls dial illumination to the cockpit dial unit, stand-by range input unit, and telescope reticle lamp.

### Radar Operator's Station

The radar operator has available the following operational controls (fig. 7–15):

1. Radar indicators. Two oscilloscopes, the A/R-scope and the E-scope, provide the radar operator with his "view" of the target.

The A/R-scope (figs. 7–15 and 7–16) has a double-trace presentation. The lower trace (A-sweep) extends from 0 yards. The range mark is movable and can be set on the target pip. Scribe marks on the scope face indicate the graduations in yards. The upper trace (R-sweep) is the expansion of the A-sweep, 500 yards either side of the range mark. The range step remains fixed near the center of the R-sweep and coincides with the range mark. Echoes from stationary targets and the 1,000-yard markers (only one of which is visible at any time) move past the range step as the target pip is moved along the A-sweep.

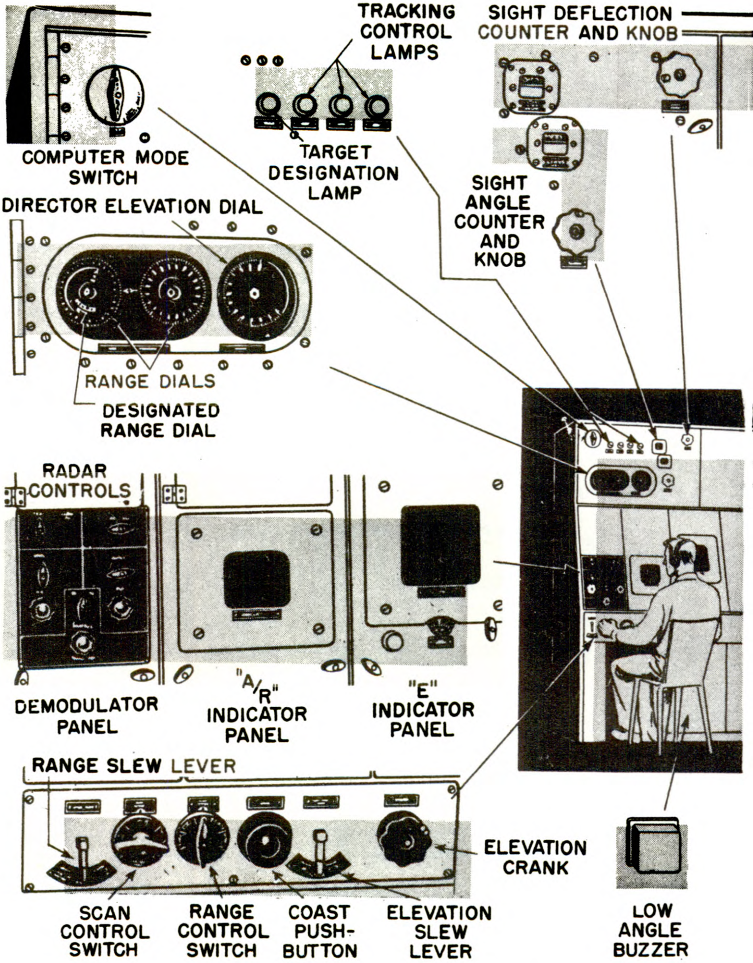


Figure 7–15.—Radar operator's operational controls.

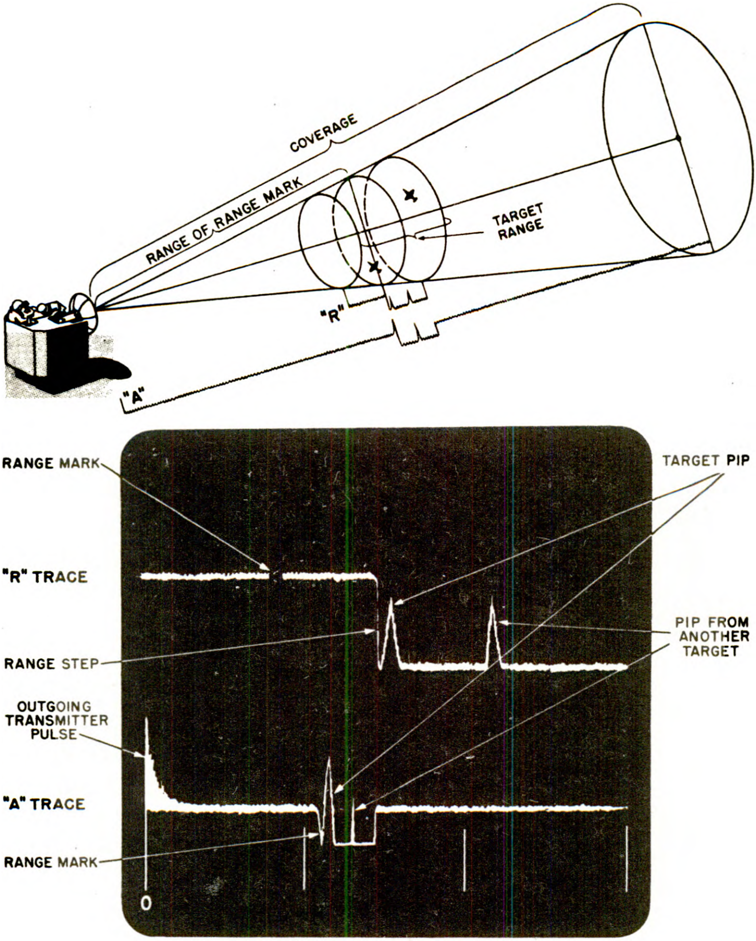


**Figure 7–16.—A/R-scope presentation.**

The E-scope (fig. 7-17) shows range (horizontally) in yards, and director true elevation (vertically) in degrees. The vertical width of the trace depends on the type of antenna scan. The range mark is a bright vertical line extending from top to bottom of the sweep. Target echoes are vertical lines in elevation. Two curved lines on the scope face furnish an indication of target altitude.

Although normal E-presentation is generally used, an expanded presentation is available by turning the elevation sweep switch to EXPANDED. Expanded sweep shows the same trace as normal, except that it is expanded in elevation and its center is fixed at the center of the scope. It gives no indication of director elevation.

Also on the E-indicator panel is the console control-indicator lamp, which is lit when the control officer has relinquished control of the director to the below-decks operators (by placing the slew switch on LOCK and the radar optical switch on RADAR).

2. The range slew lever is used for slewing the range mark to the target pip or to a designated target range.

3. The range control switch. This controls the mode of range operation. The range input signal may come from:

   a. Radar operator's range slew lever.
   b. Radar tracker's range crank.
   c. Automatic range-tracking circuit.
   d. Range memory circuit ("coast" button).
   e. Control officer's stand-by range input unit.
   f. Target designation station.

4. The elevation slew lever is used to position the director in elevation when searching for an obscured target.

5. The elevation crank controls director elevation and allows for finer control than the slew lever.

6. The scan control switch, which controls the type of antenna scan, is usually placed on the foot switch so that the scan control pedal can be used to select the type of scan.

7. The coast push button allows the system to "coast" through radar interference such as: (a) obscuring echoes from objects close to the target; or (b) radar "blind spots"

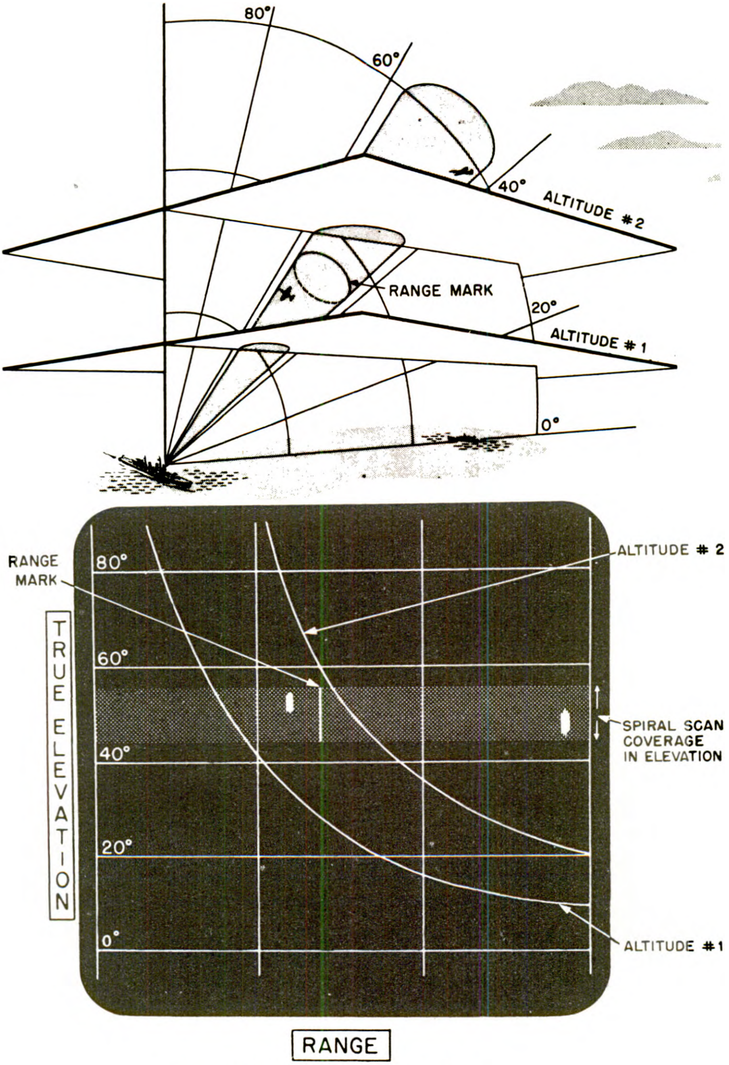


Figure 7–17.—E-scope presentation.

caused by own-ship structure. This push button cuts out the automatic tracking circuits and substitutes the memory circuits, which maintain the existing rates of motion in traverse, elevation, and range. The system will coast at these rates for as long as the button is pressed, up to a maximum time of about two minutes. However, the button should be pressed only long enough for the target pip to clear the interference. When the button is released, the automatic tracking circuits will lock back on the target pip if the beam is sufficiently close to the target; if not, the console operators must get back on target manually.

8. The radar controls are the knobs on the demodulator panel which control the operation of the radar equipment.

9. Range and elevation dials. The radar operator approximates director elevation and range from the normal E-scope presentation. For precise indications, he uses a fine and a coarse range dial, and an elevation dial which indicates elevation above the deck.

The range dials indicate the value of range being introduced to the computer (normally this is radar range). The designated range pointer indicates the value received from the target designation station.

10. The computer mode switch controls the mode of computer operation. On NORMAL, it allows the traverse and elevation tracking rates to be introduced to the computer as the rates of target motion.

On LOW-ANGLE TARGET it discards the erratic elevation tracking rates due to water reflection of radar energy when tracking targets below one-degree elevation, and substitutes a fixed zero elevation input to the computer. The traverse tracking rate is retained.

On MANUAL INPUT, which is used for long-range surface fire (in which computer lead angles and ballistic corrections are not accurate), the computer does not calculate lead angles or ballistic corrections. Instead, it used manually introduced values of sight angle and sight deflection as lead angles, combining them with director elevation and director train to produce gun orders.

11. The low-angle buzzer informs the console operators when to change the setting of the computer mode switch. The buzzer is energized:

a. When director elevation drops below one degree, if the computer mode switch is on NORMAL, and

b. When elevation rises above one degree, if the switch is on LOW-ANGLE TARGET. Changing the switch setting silences the buzzer.

12. The target-designation indicating lamp is controlled from the target-designation station. When lamp is lit, that station is transmitting range and bearing of a designated target.

13. The tracking-control indicating lamps indicate the settings of the control officer's slew switch and radar-optical switch.

14. The sight-angle and sight-deflection knobs and counters are used during long-range surface firing when the computer is operating in manual input. The sight-deflection counter is calibrated in mils; its zero setting is 500. The sight-angle counter is calibrated in minutes; its zero setting is 2,000. For normal operation of the system, both counters are set to their zero settings.

### Radar Tracker's Station

The radar tracker has available the following operational controls (fig. 7–18):

1. The system power controls are the various push buttons and indicating lamps with which the radar tracker controls power to the system. They are located on the console synchronizer panel to the right of the radar indicators.

2. Radar indicators are the radar tracker's "view" of the target, obtained from the E-scope and the B-scope. Since the B-scope covers a range interval of only 2,000 yards, the radar tracker, when searching for a target, watches the E-scope to help the radar operator spot the target pip. Otherwise he directs his attention exclusively to the B-scope.

The B-scope presentation (fig. 7–19) shows bearing (horizontally) either side of director train, and range (vertically) 1,000 yards either side of the range mark. The trace appears

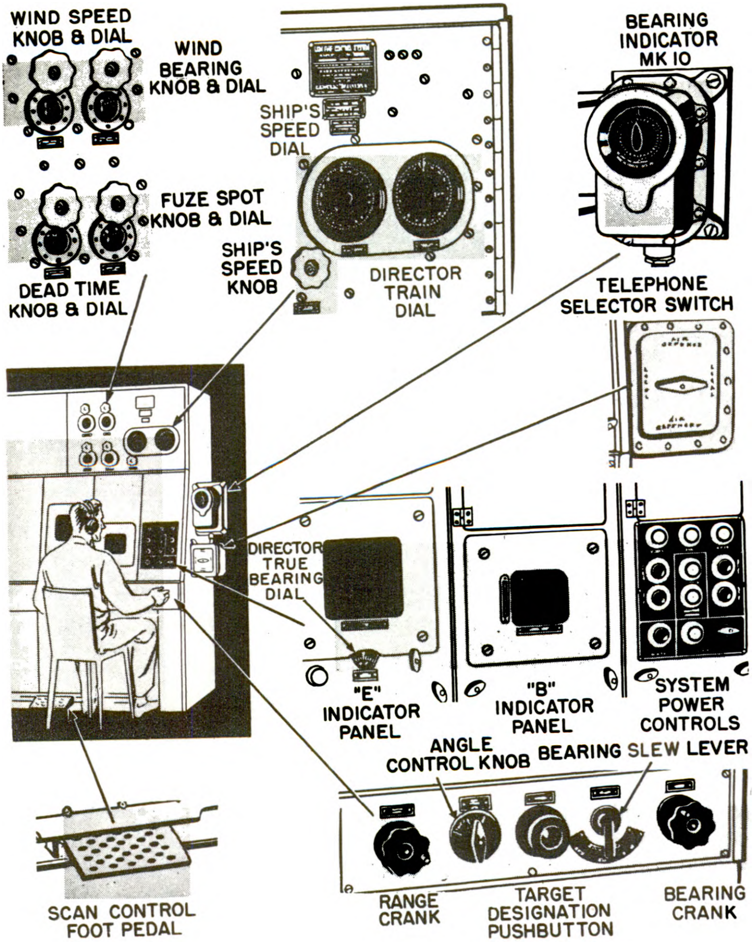


Figure 7–18.—Radar tracker's operational controls.

as a vertical band, the center of which is always at the center of the scope. The width of the trace in bearing depends on antenna scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target pips appear as horizontal lines of length equal to a few degrees of bearing.

For the pip to be visible on the B-scope, the range mark must be within 1,000 yards of the target pip. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the pip up or down to the range line, and simultaneously turns the bearing crank to bring the pip right or left to the director bearing line.

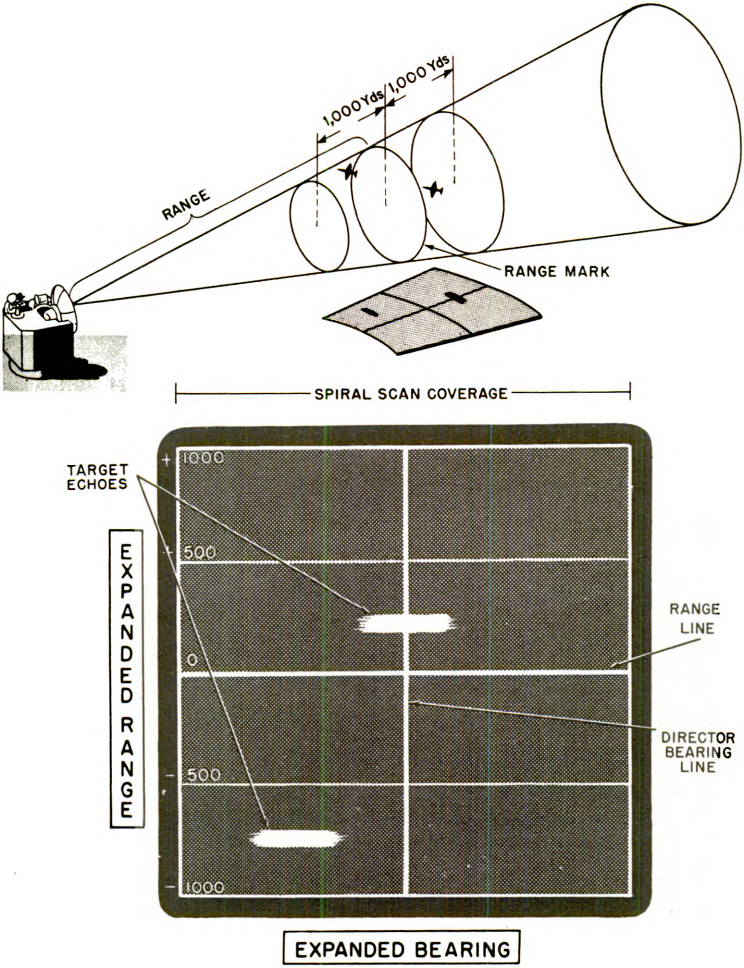


Figure 7–19.—B-scope presentation.

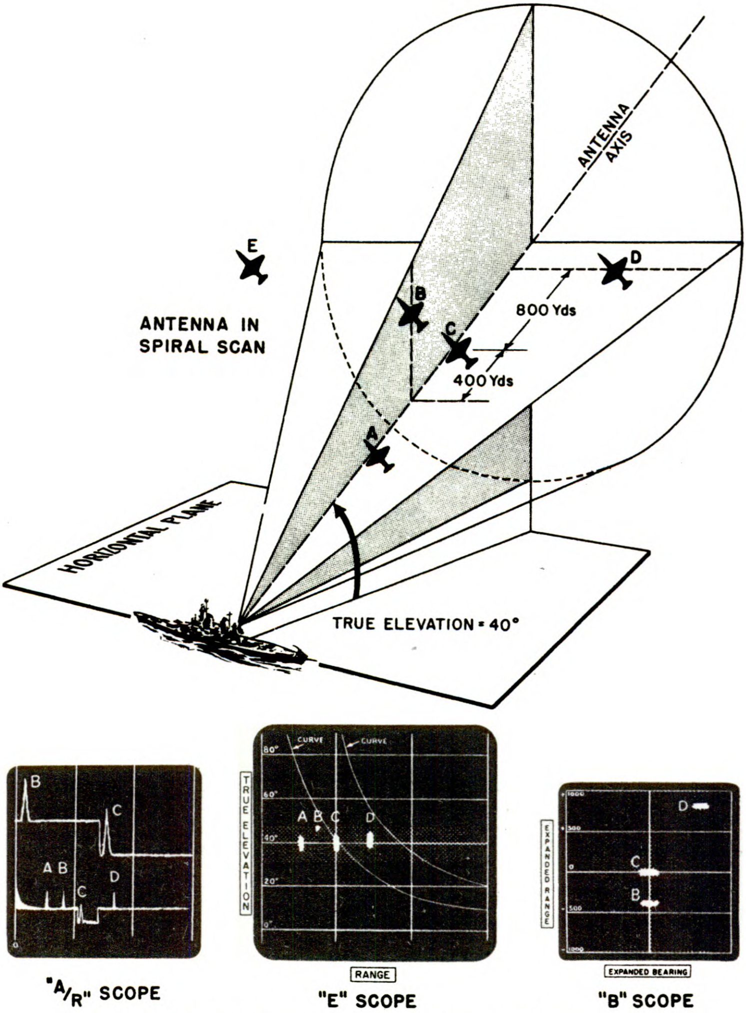


Figure 7–20.—Interpretation of radar scopes.

Figure 7–20 shows the appearance of all three radar scopes for different positions of the target. The equipment is tracking target *C*; therefore the pip from target *C* is against the range mark on the A-sweep, at the step on the R-sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the spiral scan appear on the A-sweep and E-scope. Target *E* does not appear on any scope because it is too far from the antenna axis. Target *A* does not appear on the B-scope because it is more than 1,000 yards from the range mark. Targets *A* and *D* do not appear on the R-sweep because they are more than 500 yards away from the range mark.

3. The telephone-selector switch. By means of this switch, the radar tracker can talk on either the air-defense circuit or the local circuit. Normally, he stays on the air-defense circuit, so that he can hear designations from the air-defense or target-designation stations. He switches to LOCAL only to communicate directly with the director operator or gun captain.

4. The range crank positions the range mark on the target pip. One revolution of the crank changes the position of the range mark by 100 yards.

5. The bearing slew lever slews the director in train.

6. The bearing crank positions the director in train. It is used for more sensitive control of director train than is provided by operating the slew lever.

7. The angle control switch is used for radar tracking of surface targets. With this switch on SURFACE, the director is automatically positioned at 0° true elevation by a fixed signal, and the automatic tracking circuits are cut out. Tracking in bearing is performed by means of the bearing crank, which, in this case, is operative both in conical and in spiral scan. The switch is usually left on NORMAL.

8. The target-designation push button, when pressed, automatically synchronizes the director with designated target bearing.

9. The scan control pedal controls antenna scan when the scan control switch is on FOOT SWITCH. The radar tracker selects SPIRAL when searching and CONICAL when tracking. To change from one to the other, he presses the pedal which is a sequence-type ("press-to-change") switch. The only visible indication of whether the pedal is on SPIRAL or CONICAL is the width of the trace on the radar indicators.

Operation of the automatic tracking circuits is interlocked with the type of antenna scan. Automatic tracking in bearing, elevation, and range is possible only in conical scan. Also, automatic gain control normally depends upon conical scan.

In spiral scan, only manual tracking is possible. The elevation slew lever and hand crank and the bearing slew lever and hand crank are not operative in conical scan except when the angle control switch is on SURFACE.

10. The director bearing dials. The radar tracker receives indications of director bearing from three dials. The true-bearing dial on the E-indicator panel shows the bearing of the director from true north. The director-train dial on the console right-hand dial panel shows relative director bearing (relative to bow of own ship), and designated relative target bearing. Bearing Indicator Mk 10, attached to the right side of the console, shows both true and relative director bearing on the same dial face.

When bearing is designated, the tracker may slew the director to match the zero of the director-train dial with the designated bearing pointer. Normally, this is done automatically by pressing the target-designation push button.

When bearing is designated by telephone only, automatic synchronization is not possible and the designated-bearing dial is disregarded.

11. The ship-speed knob and dial is used to set ship speed into the computer. The radar tracker sets this value into the computer by matching pointers.

12. The wind-speed and wind-direction knobs and dials. The radar tracker sets true wind speed and true bearing of true wind into the computer manually, in accordance with values received by telephone.

13. The dead-time knob and dial. The radar tracker sets dead time into the computer manually by turning this knob. The dial is graduated in seconds from 2 to 6.

14. The fuze-spot knob and dial. By means of this knob, the radar tracker manually introduces range-spot corrections, from the control officer or the radar operator.

## SUMMARY OF OPERATIONAL CONTROLS—TRACKING CONTROL SWITCHING

All signals for positioning the director are introduced to the gyro unit, where they are combined with the stabilizing signals and then transmitted to the director drives.

The slew switch takes precedence over all other switches. When on SLEW, it allows only the signals from the slewing sight to be introduced to the gyro unit. For any other unit to have control, the slew switch must be on LOCK.

Next in importance after the slew switch is the radar-optical switch. When on OPTICAL, it selects only the signals from the tracking control unit; when on RADAR, it allows signals from the console to take over.

The target-designation push button takes precedence over all other console controls. When pressed, it selects the designated bearing signal from the target-designation station and a fixed signal of 0° true director elevation or, on later systems, a designated elevation signal. On NORMAL, the target-designation push button allows other console controls to operate.

With the angle control switch on SURFACE, the director is positioned at 0° true elevation; in bearing, the director is positioned by operating the bearing crank or bearing slew lever.

When the bearing slew lever is being operated, signals from the bearing crank are cut out; the bearing crank is operative only if the slew lever is on NORMAL. Similarly, the elevation crank is operative only if the elevation slew lever is on NORMAL. When the angle control switch is on NORMAL, these slew levers and cranks are operative only in spiral scan, the scan control pedal serving its auxiliary function of choosing between manual and automatic tracking.

Automatic tracking is possible only in conical scan. The memory circuits are substituted for the automatic tracking circuits when the coast push button is pressed. The automatic tracking circuits will control the director if: (1) the coast push button is on NORMAL; (2) the scan control pedal is on CONICAL; (3) the angle control switch is on NORMAL;

(4) the target-designation push button is on NORMAL; (5) the radar-optical switch is on RADAR; and, (6) the slew switch is on LOCK.

COMPUTER MODE SWITCHING. The elevation and traverse rates introduced to the computer for computing lead angles are the same as those transmitted to the gyro unit for positioning the director. However, the computer does not receive slewing rates nor, generally, rates from the console cranks.

The only traverse and elevation rates received by the computer are those from: (1) the tracking control unit, (2) automatic tracking circuits, (3) memory circuits and, (4) in a special setting for surface fire, the bearing crank and zero elevation circuit. The rate from the bearing crank is introduced to the computer only if the scan control pedal is on SPIRAL and the angle control switch is on SURFACE (although it will be transmitted to the gyro unit to position the director regardless of the type of scan control when the angle control switch is on SURFACE).

In order to introduce any one set of these rates to the computer, the computer mode switch must be on NORMAL. Lead angles are computed from these rates, ballistic corrections added, and the total lead angles transmitted to the gun order converter, where they are combined with director train and elevation. The resultant gun orders are then transmitted to the gun. With the computer mode switch on LOW-ANGLE TARGET, gun orders are produced in the same manner, the only difference being that any elevation rate input is cut out and a zero elevation rate substituted.

When the computer mode switch is on MANUAL INPUT, all rate inputs are cut out and the computer calculates no ballistic corrections. Instead, the manually introduced values of sight angle and sight deflection are introduced to the gun order converter in place of the total lead angles. Sight angle and sight deflection are combined with director train and elevation to produce gun orders.

# QUIZ

1. What is indicated on a T & E-indicator scope of a Mk 34 radar system when the system has no returned echoes gated?
2. In what position must the range selector switch on a Mk 34 radar system be in order that the operator may see all targets in the entire range of the system?
3. How are the director line of sights and the radar antenna in a Mk 56 system stabilized?
4. In what plane are the values of *RdE* and *RdBs* measured in the Mk 56 system?
5. What is the primary purpose of the vertical gyro used in the Mk 56 system?
6. The voltage produced by the tachometer attached to the shaft of the range servo motor is a measure of what quantity in a Mk 56 system?
7. What is the purpose of the axis converter as used in the Mk 30 computer?
8. What are the three values provided by the Mk 35 radar to the Mk 56 GFCS?
9. What is the primary function of the Mk 42 computer used in the Mk 56 GFCS?
10. What value does the chronograph measure in the Mk 56 GFCS?
11. Where is the radar antenna mounted in the Mk 63 GFCS?
12. The director of the Mk 63 GFCS is trained and pointed by what means?
13. What is the angular displacement the antenna may be offset from the bore axis in the Mk 63 GFCS?
14. According to the Mk 63 flow diagram, from where does the TACU receive true director train?
15. What is the solution time for the AA fire-control problem in the Mk 56 GFCS?
16. How many people are required to operate the GFCS Mk 56?
17. How are you assured that the power is off to the amplidyne generators when the Mk 56 director is secured in train and elevation?
18. In the Mk 56 GFCS, which switch takes precedence next after the slew switch.

# CHAPTER 8

## GENERAL MAINTENANCE

Fire-control instruments are high-grade precision equipment and must be given proper care and lubrication. Undue wear on the equipment can and should be avoided by correct usage. Correct operation, handling, and care will go a long way toward increasing the life of fire-control gear.

You, as a senior petty officer, will find that one of your most important jobs will be to supervise the operation, routine, maintenance, and tests of the equipment on your ship. Under normal circumstances you will have experienced men under your direction; however, since circumstances are not always normal, you must be willing and able to take over at any time in matters of routine. That is why the following is directed to you.

Detailed descriptions and instructions regarding correct installation, operation, lubrication, care, and upkeep of fire-control equipment are contained in ordnance pamphlets, ordnance technical instructions, and NavOrd Instructions and Notices. NavOrd Instructions and Notices will now replace NavOrd OCL's which have been discontinued. The OCL's listed in OP O will remain in effect until superseded or declared obsolete. The following general rules are also essential to maximum operating efficiency and minimum maintenance:

1. Every Fire Control Technician must be thoroughly acquainted with the detailed operational and maintenance instructions contained in ordnance publications applicable to the equipment in his battery.

2. All instruments must be inspected periodically, including extras and repair parts. Instructions for this inspection

of instruments in store are issued from time to time by the Bureau of Ordnance.

3. Repair parts and instruments must be stored in dry, dustproof compartments to insure protection from weather as well as from examination by unauthorized persons.

The above is based on excerpts from the Bureau of Ordnance Manual. It is strongly recommended that you read chapter II of this manual.

## MOISTURE, CLEANING, LUBRICATION

The battle against the effects of moisture is never-ending, but the results will be more satisfactory if a few simple precautions are taken. Moisture carried by salt air creeps into the smallest openings and causes corrosion of the worst kind, so always keep water-tight covers in place. This means keeping covers and protective canvasses on in foul weather. Even inspection covers should not be removed in damp weather unless it is absolutely necessary. Keeping electrical circuits energized during periods of extreme dampness will help to reduce the amount of moisture they absorb.

Secondly, keep your equipment clean and free of dirt or other foreign matter. This will reduce the chances of corrosion. Oil and grease also cause deterioration of electrical insulation, with consequent undesired grounds and other electrical trouble.

The third preventive maintenance measure to be considered here is lubrication. Much of the lubrication required for fire-control equipment is for the purpose of preventing rust, oxidation, and corrosion. However, the prime purpose of lubrication is to reduce friction between moving parts. Oil and grease are normally used sparingly because too much lubrication can be harmful to electrical wire insulation and gasket material. For this reason, instruments should be wiped free of oil periodically to reduce the collection of grit and dirt. Ordnance publications applicable to the particular equipment under consideration will tell you when to lubricate, what type of lubricant to use, how much to use, and where to put it.

The types of lubricants used are referred to in OP's by Bureau of Ordnance specification numbers. These specifications are changed from time to time by direction of NavOrd Instructions. For example, an instruction may direct that lubricant specification "so and so" used on certain equipment should be discontinued, and that you should shift to the lubricant specified in the letter. This you must do because it means that the Navy has developed a better lubricant for the particular use. Thousands of dollars have probably been expended developing this new lubricant, and it has proved more suitable than the one it replaces.

The following circular letter, which is still in effect, was taken from the *Navy Department Semi-monthly Bulletin*, dated 21 July 1947. This type of letter keeps your gunnery officer up to date on changes and improvements in lubrication techniques. Read it carefully as it contains valuable information on the latest types of lubricants and the places used.

BUREAU OF ORDNANCE CIRCULAR LETTER NO. F3–47

Subject: Lubrication of Fire-Control Instruments for Service Use and for Long Term Storage.

Ref: (a) Instrument Oil, BuOrd Specification, 14–0–20 (Ord), (formerly OS1647), Standard Stock Number 14–0–975–25.

(b) Instrument Grease, BuOrd Specification 14–G–8 (Ord), (formerly OS1648), Standard Stock Number 14–G–980–800.

(c) Bearing Grease, BuOrd Specification 14–G–10 (Ord), (formerly OS1350), Standard Stock Number 14–G–715 or 14–G–720.

(d) NavOrd List No. 19742—Lubricants for Ordnance Equipment on Naval Vessels.

1. The Navy has recently developed two (2) synthetic lubricants, reference (a) and (b), for general purpose lubrication of instruments. These new lubricants have excellent rust inhibitors and anti-oxidants, a wide operating temperature range, and an extremely low rate of evaporation. These combined properties provide an oil and a grease for general

use in ordnance instruments that is very superior to the numerous other lubricants now in use.

2. It is requested that as soon as availability of supply permits, lubricants, references (a) and (b), be used in place of the various previously prescribed proprietary and specification lubricants for light fire-control instruments within the following limitations:

(a) "Light Fire-Control Instruments" are to be considered as those containing synchros, gyros, computing mechanisms, control devices, and other lightly loaded mechanisms. Examples of mechanisms which would be lubricated with the synthetic instrument oil and grease are as follows:

(1) Ring dial bearings
(2) Small shaft bearings
(3) Synchro stator and rotor bearings
(4) Integrator bearings and disk
(5) Lightly loaded gears
(6) Multipliers
(7) Slides
(8) Pivots
(9) Component solvers
(10) Limit stop screws

(b) The choice of oil or grease in the lubrication of any particular piece of equipment shall be determined by the type of lubricant previously prescribed; that is instrument oil, reference (a), shall be used where oil was specified and instrument grease, reference (b), shall be used where grease was specified on the applicable lubrication charts or other prescribed lubrication instructions.

(c) Suitable synthetic lubricants are not presently available for heavy load applications, high temperature applications, extreme pressure applications, or for watch and clock mechanisms. Pending availability of more suitable synthetic lubricants, use of presently prescribed lubricants shall be continued in fire-control equipment for the following applications, with the exception of those lubricants specified in paragraph 4 below:

(1) Heavily loaded gears and bearings
(2) Electric power motors
(3) Gear boxes and heavy shafting
(4) Heavy duty roller paths

(5) Gyro wheel & bearings
(6) Watch & clock mechanisms

3. Instrument oil, reference (a) is now available in standard stock, and vessel allowances are contained in reference (d). Instrument grease, reference (b), is not immediately available in standard stock, but is under procurement and when available in the near future, will be added to allowance lis reference (d). Pending its availability, bearing grease, reference (c) should be used as a substitute therefor.

4. Certain proprietary lubricants have been found to be deficient in oxidation stability to the extent that their failure in storage due to oxidation would be probable. Accordingly, it is directed herewith that use of the following lubricants be discontinued in all fire-control equipment:

Freezene medium refrigerating oil
WS511 Grease
Univis 48 oil
Gulf Precision Greases No. 1 & No. 2.

—BuOrd M. F. Schoeffel

## Daily Maintenance Routine

If all fire-control equipment, including connecting cables, could be enclosed in a dehydrated chamber and protected against shock and vibration, perhaps daily checks would not be so important. Since the equipment is not enclosed, good preventive maintenance practice requires that you OPERATE and TEST all equipment and instruments DAILY.

Most ships have check-off sheets for the purpose of recording the results of these daily tests. By keeping a record, a handy reference is afforded in the event of a failure. Of course, all ships have a fire-control machinery history in which are kept records of all repairs and alterations, but this is too detailed to analyze quickly. By keeping a record of your daily tests, not only will you have a record of your tests as they are run, but you will be the first one to know of a trouble. By keeping minor routine troubles eliminated through daily tests and maintenance procedures, you will find that major failures seldom occur. Your equipment will always be ready for any emergency or practice.

## SUMMING UP

1. Inspect all instruments periodically for moisture, dirt, oil and grease. Clean them if any is present.
2. Lubricate according to applicable instructions.
3. Keep instruments that are exposed to weather properly covered, and watertight covers secured.
4. Operate daily all equipment in all possible combinations.
5. Keep a record (check-off sheet) of the daily tests.
6. Keep index cards on the instruments under your supervision and see that the instruments receive the required care.
7. Keep all repair parts in a clean, dry storeroom and make frequent checks on them so that they are always serviceable.

## REPAIR AND OVERHAUL OF F. C. INSTRUMENTS

Repair ships and tenders are equipped to undertake the routine overhaul and repair of fire-control equipment carried by the various types of vessels which they service. Normally, Navy yards are only called upon to repair or overhaul fire-control equipment during a ship's overhaul or in the event of major overhaul; these repairs are often made by the representatives of the manufacturer of the equipment. Major repair or overhaul should never be attempted by any other than fully qualified and authorized personnel from tenders, repair ships, Navy yards, or private concerns. Authority for major overhauls is obtained from the Bureau of Ordnance.

When you or your men find through daily tests, routine inspections, or failure during use, that some instrument or piece of equipment is in need of repair, do your best to determine what is at fault and make a full report to your division officer, or directly to the gunnery officer before decommissioning any instrument for repairs. In the event the trouble is beyond own ship's force facilities, it will be necessary to call in repair technicians from a repair ship or base. In most cases these technicians will be able to locate, repair the defect, and make the required adjustments; you will be expected to assist in most cases. There are times, particularly on new types of equipment, when repair ships will not attempt or are not authorized to attempt repair and adjustment. Under these circumstances it is up to the gunnery officer to put through a work request to the ship's home Navy yard where experts or factory representatives will do the job.

## PAINT FOR FIRE-CONTROL INSTRUMENTS

The only paints recommended for fire-control instruments are fire-control gray and black enamels. The Bureau of Ordnance has conducted tests and found these to be the best for all types of conditions. Instruments exposed to the weather are the only ones that should ever require painting, and if they are kept properly protected during foul weather they stand up remarkably well. Practically all fire-control instrument cases are cast aluminum with a baked fire-control enamel finish applied at the factory. This finish is very hard and glossy and the cast aluminum is especially corrosion resistant.

To sum up, paint instruments only when it is absolutely necessary. Painting a whole instrument because of a few scratches, chips, or worn spots may make it look better for a short time, but in the long run it's a waste of time. When it is necessary to paint, be sure the surface is scraped and wire brushed clean; use only the recommended fire-control enamels and be sure you have a good undercoating on the bare metal.

## PACKING AND TRANSPORTING

When it becomes necessary to ship or transport an instrument, it must be packaged properly to prevent shock and exposure to the elements. If possible the original shipping container should be used, since it will have the proper mountings to hold the instrument rigidly in place. Upon completion of packing, stencil the container with HANDLE WITH CARE—DELICATE INSTRUMENT.

The gunnery officer and the chief will prepare the necessary shipping papers.

## INSTALLATION

During the installation of fire-control equipment, the gunnery officer or his representative will inspect or supervise the work to see that it meets the specifications of the Bureau of Ordnance. Since you may be one of his assistants, you must also familiarize yourself with the necessary requirements. Many headaches can be avoided if the initial installation is correct and the proper inspections are made at the time of the installation. Don't hesitate to report any discrepancies you note to the gunnery officer.

## REPAIR PARTS FOR FIRE-CONTROL EQUIPMENT

Repair parts are provided for all fire-control instruments as follows: one set of vessel repair parts for every ship; one set of tender and one set of shore-base repair parts for each group of 8 destroyers, 4 cruisers, or 12 submarines; and one set of shore-base repair parts for every 2 battleships. Vessel repair parts are issued to ships in accordance with allowance lists and are usually delivered to the ship during initial fitting out at the navy yard.

Because replacement repair parts for fire-control instruments are only available in limited quantities and are difficult to procure, it is important that you reduce the need for replacements to a minimum. This means close adherence to approved maintenance practices at all times.

Fire-control storerooms must be dry and so arranged that repair parts are readily available for use, inspection, and inventory. Fire-control storerooms are seldom constructed for that purpose, so it will be up to you to make use of your ingenuity and arrange them to your advantage.

A simple filing system for keeping track of repair parts is a time-saver and a convenience. Here's how it can be done:

1. Number each box or bin.

2. For each box or bin keep an indexed folder with the following information in it: (a) what equipment the parts are for, (b) the box or bin number, (c) what repair parts are in the box or bin, (d) what should be in it (this will be

the allowance list), (e) where the missing repair parts were used, (f) what has been ordered, (g) what is to be ordered, and (h) the date that previously ordered parts are received. With a system like this, you will be able to tell in a few minutes whether you have a certain repair part, where it is, and if you don't have it, when it was ordered. Obviously such an index would take the toil out of an inventory since you have at hand a continuous inventory.

## FIRE-CONTROL TESTS

Fire-control tests apply to all the equipment on the ship for which the fire-control division is responsible. So far, the discussion of tests has been very general in nature because the idea has been to show how vital these tests are to proper maintenance. Now let's be more specific and enumerate the tests you will be required to know about.

1. Transmission tests. (Daily.)
2. Computer and rangekeeper tests. (Semi-monthly.)
3. Operational tests of equipment not included above. (Daily.)
4. Dynamic accuracy tests. (Periodically or when directed.)
5. Alinement checks. (When directed.)

These are only a few of the tests that are run on fire-control equipment. There are weekly, semi-monthly, monthly, quarterly and semi-annual tests. These will vary according to the installation, and it will be necessary for you to consult the applicable ordnance publications for detailed information when directed by the gunnery officer.

## TESTING THE RANGEKEEPER OR THE COMPUTER

### ("A" Tests)

In the transmission test it is necessary to use the output of the rangekeeper or computer; however the accuracy of their computing sections and the accuracy of their generated quantities must be checked by still other tests. These tests come under the headings of STATIC TESTS and GENERATION TESTS.

STATIC TESTS, called "A" tests, are similar for all machines so only a general description is given here. The "A" tests check the entire computing mechanism of the machine, including the deck tilt, trunnion tilt, and ballistic computers. It will not check the integrators because "A" tests are run with the time motor OFF. Without the time motor on, the machine is at rest, so the tests are called static tests.

Standard "A" test sheets are furnished all ships by the manufacturer for every rangekeeper or computer. These sheets list a considerable number of problems (15 in fact), one problem to each line on the sheet. In separate columns, on each line, are listed values of independent variables which are set into the machine such as wind, target and own ship motions, director train, powder charge and *I. V.* settings, spots, level and cross-level, and present range. These variables are set in carefully with the power ON but the time motor OFF.

The "A" test sheet is a rather bulky affair, too bulky to be reproduced here; so right now is a good time to go to your chief or division officer and get one to use in conjunction with this text. At the same time it would be well to obtain a "B" or "C" test sheet for reference later. The OP on most any rangekeeper or computer includes these test sheets.

The answers which are read from the machine and entered on the sheet are $E'g$, $B'gr$, $Vs$, $Ds$, and $Vz$ and an AA computer will also indicate $F$, fuze. For each of these quantities the test sheet lists the theoretically correct solution, the class $B$ error, and the solution computed for the machine. Then columns are provided for entering the value you read off the machine, and for the observed class $A$ error. In addition, values are included for certain intermediate quantities, such as advanced range $R2$ and observed relative target bearing $Br$. These intermediate quantities are used to analyze errors when the class $A$ errors exceed the allowed limits. Do not confuse class $A$ errors and class $B$ errors with "A" and "B" or "C" tests. Class $A$ errors result from faulty adjustment or wear. Class *B* errors, resulting from the design of the machine, are due to linear approximations which reduce the size and simplify the mechanism of the machine.

The "A" test sheet shows the maximum allowable class *A* error for each of these quantities (answers such as $E'g$ and $B'gr$). It also shows the allowable average error. The average class *A* error is obtained by adding all the readings, disregarding signs, and dividing by the number of readings. If the average error is equal to or less than that allowable, and if none of the errors exceed the ALLOWABLE MAXIMUM, the machine has passed the test.

Should the AVERAGE OR MAXIMUM ERRORS fail to fall within the allowable, the intermediate quantities should be checked in determining the part of the mechanism that is at fault.

Let's take an example. $B'gr$ in the Mk 8 rangekeeper is in error by an almost constant amount on all problems. This is easy, because if the error were due to anything more than a dial adjustment, it wouldn't be constant. In this case, probably all that would be necessary would be to make the $B'gr$ dials read zero when all the inputs going to make up $B'gr$ were set on zero.

Such an error is simple to figure out, so let's take one not so easy. $B'gr$ is again in error in the final analysis; that is, it is over the allowable limits. Upon examination you find that the errors are not constant. Some problems may be greatly in error, and in other problems the error is within allowable limits. This may seem puzzling, but if you think back a bit in this course and recall what makes up the quantity $B'gr$, the problem will be easy. Gun train order $B'gr$ is equal to director train $B'r'$, plus the total deflection in the deck plane, $Dd'$. Furthermore, $Dd'$ is the addition of trunnion tilt train correction $Dz$, and sight deflection $Ds$. You must consider the intermediate quantities one at a time.

The first thing to check is the $B'r'$ input. If it's wrong, check the $B'r'$ follow-up for improper operation. Next, after assuring yourself that this is not the cause, check the readings of $Ds$ and $Dz$ on the test sheet. The trouble will necessarily have to be in one of these two, so note which quantity the error is in and check its follow-up. Let's say it's in *Dz*, and that the follow-up is working satisfactorily. Then, of course, we have it traced to the trunnion tilt corrector because that's where *Dz* originates. To further trace the exact source of the error, it is necessary to run the trunnion tilt corrector tests found in the O. D. on the rangekeeper. These tests would indicate what adjustments are to be made. Further reference to the adjustment section of the O. D. will tell how to make these adjustments.

Now if the error had been found to be in *Ds*, the same procedure would have been used to trace it down. First analyze the test sheet for possible sources of error; then, referring to the schematic, find out what goes in to make up *Ds*. Finally, eliminate each unit involved until the source of error is found. After making any adjustment to correct an error, run a full set of tests to be sure of your work, and make a detailed report.

### The "B" and "C" Tests

The "A" test gives you a check on all the rangekeeper calculations except those performed by the integrators. These are checked by means of the "B" and "C" tests.

The "B" test offers the most direct test, but it cannot be used on a regenerative machine like the Mk 8. It is used on non-regenerative machines like the Mk 1 and Mk 1A computers. In the "B" test, fixed values are assigned to the range, elevation, and bearing rates by setting up own ship and target courses and speeds. Then you observe whether the rate of movement of the generated bearing and range dials agree with these values.

In a regenerative machine, as you learned, the generated changes in bearing and range feed back to the own ship and target component solvers, changing the values of the rates which were originally introduced. Therefore, the "B" test cannot be used on this type machine.

In its place and for the same purpose you use the "C" test. In this test you actually set the problem of relative motion into the machine, setting in target and own ship motion and initial values of bearing and range. Then you allow the machine to generate the continually changing values of range and bearing. You will notice on the left of the "B" or "C" test sheet a small sketch showing the problem which is being run.

The procedure for "B" or "C" tests is as follows:

1. Set up the values of target and own ship course and speed given on the test sheet for the problem.
2. With the time knob IN, set the time dials at zero.
3. Set up the initial values of generated range, bearing and elevation (elevation is set in on an AA computer).
4. With the MANUAL time crank engaged, start the time dials turning. Be sure to start smoothly and gradually in order to prevent the time input to the integrators from slipping and introducing an error. As the dials come up to speed, turn on the time motor switch.
5. When the dials read about 25 seconds, turn off the time motor and bring the time dials to exactly 30 seconds with the manual time crank.
6. Read and record the values of generated range and bearing. This step applies to the Mk 8 only. The "B" tests on the AA computers consist of three sets; one set for range, one for bearing, and one for elevation.
7. Repeat steps 4, 5, and 6 until the test is completed. (OP's call for from 10 to 20 readings, one every 30 seconds).

Now you compute the errors. In the column headed "total error" enter the difference in the calculated reading and the actual reading. The size of the total error alone does not tell you much because total error could become most any value by just allowing the problem to run indefinitely. However, from a series of total error readings you can find out what the rate error is for a given period of time by computing the DIFFERENCE between the total errors at the end of each minute.

So, in the column headed "rate error," enter the DIFFERENCE between total error at each reading and the total error one minute earlier. If the total error is decreasing (or is negative and becoming more negative), you enter the rate error as a negative number. After you have the rate error per minute figured, total all the rate errors per minute and take the average. Place the average and the maximum error in the space provided. Note whether or not the average and maximum readings fall within the allowable limits. If they do, the test is acceptable; if not, some adjustment is necessary.

You will find that locating the source of an error in the integrators is a rather simple matter. First, the tests plainly indicate in which section the trouble lies. For example, let's say bearing rate is out on your Mk 8. You have just completed a set of "A" tests which came out all right. By looking at the schematic of the rangekeeper you will see that the bearing integrator has two inputs—*T/cR* and *RdBs*. To check the *RdBs* input, place all speeds on zero and start the time motor; if the bearing dials move you have located the trouble. The "A" tests were all right. This indicates that the component solvers are in adjustment and so it is deduced that the *RdBs* input to the integrator is in error. Refer to the O. D. for adjustment procedures and make the *RdBs* input adjustment. Then run the test again; continue this procedure as many times as is required to get the correct output.

In the event the *RdBs* input was correct you must trace out the other input *T/cR*. From the schematic you can see that two quantities make up *T/cR*; time from the time motor and inverse range, and 1/*cR* from the inverse range cam. In the O. D. you will find both time tests and 1/*cR* tests. Run these two tests to locate the error, and then turn to the section in the O. D. on adjustments and correct the error.

There is a "C" test for the Mk 1 and Mk 1A computers which is similar to the "C" test for the Mk 8, but in the "C" test for the computers the director is energized and placed in automatic, making in effect, a regenerative rangekeeper out of the Mk 1.

You've probably noted that there are tests for rangekeepers and computers other than those mentioned here. You should obtain the O. D. on the particular installation on your ship and find out about them.

### Frequency of the "A" and "B" or "C" Tests

In normal operating conditions a complete set of tests of each type taken twice a month will prove sufficient.

Running a full set of tests daily or during each watch is NOT NECESSARY, and will cause increased wear on operating components. A full set of tests should be run before entering a navy yard for overhaul or whenever trouble is suspected. Navy yard technicians will use these tests as guides for adjustment and repair.

## OPERATIONAL TEST OF AUXILIARY EQUIPMENT

This is a broad heading and is meant to emphasize the fact that ALL the fire-control equipment aboard ship should be tested periodically as well as that equipment included under the transmission and rangekeeper or computer tests. The following lists a few items that will not necessarily be checked by the other tests although they can and should be tested by the operators on stations at the time of the transmission test.

1. Stable elements and stable verticals.
2. Fire-control radars and antenna drive mechanisms.
3. Turret and director rangefinder stabilizers.
4. Turret and director rangefinder shutters and sight port openings.
5. Lead computing sights.

The tests for the above equipments are described in the OP's on the gear.

## OPTICAL INSTRUMENT CARE AND MAINTENANCE

As with other fire-control instruments, you will find optical instruments are delicate and precision made. Replacements are available in very limited quantities, and therefore correct operation and proper maintenance are essential.

You learned about the maintenance of optical instruments in your third class book; a review, however, may be helpful at this time. Also, detailed descriptions and instructions as to the adjustment, care, and upkeep of optical instruments are contained in ordnance pamphlets, and will be supplemented from time to time by NAVORD Instructions and Notices.

## GENERAL RULES FOR OPERATION AND MAINTENANCE

1. All operating personnel must be thoroughly acquainted with detailed operational and maintenance instructions; these instructions must be carried out to the fullest extent that operating conditions permit.
2. All instruments, including those in store, should be inspected periodically. This should always be done when the services of an optical repair shop are available in order that the maximum benefit can be obtained from the opportunity.
3. Spare instruments are to be securely stored in a dry storeroom and maintained in a ready condition.
4. Repair or disassembly of optical equipment should never be attempted by other than qualified optical repairmen unless it is absolutely necessary. Correct reassembly of optical equipment can only be accomplished in repair shops where the necessary collimating equipment is available.
5. Take full advantage of optical repair facilities whenever they are available.
6. Surveyed instruments should be turned into the nearest optical repair shop for salvage of usable material.

### Gas and Dry Air in Optics

One of the most frequent difficulties with optical equipment is the formation of moisture on the lenses; this is particularly true when they are subject to rapid changes of temperature. The best protection against moisture is to see that the instruments are properly dried and gassed at regular intervals.

This is accomplished aboard ship either by Opticalmen from a repair ship or by the ship's Opticalmen and Fire Control Technicians. Before gassing, air is passed from a cylinder under approximately 600 p.s.i. through a reducer and through the optical instrument (air at 600 p.s.i. is practically free of moisture), until the moisture can no longer be seen or at least fifteen minutes if no moisture was visible in the first place. This drying process is followed by a flushing with some inert gas such as helium. Then the exhaust valve is closed and the instrument is filled with helium at a pressure of from 3 to 6 p.s.i. For instruments not filled with gas the drying process alone is carried out at periodic intervals or oftener if necessary to keep the instrument free of moisture.

It is sometimes possible to remove the protective glass on periscopes and lead computing sights and wipe the moisture off with lens paper. This method is not recommended except in emergencies, when there is no time for some other method; then only an experienced man should attempt it.

### Cleaning Lenses

When painting around optical equipment, care should be exercised to keep paint off lenses and to wipe off paint specks immediately. In extreme cases alcohol may be used to clean lenses, but it should be used sparingly because alcohol is a solvent for cement. The best way and most convenient way is to use your own breath, followed by a brisk polishing with lens paper. For removal of smoke particles and dust use a soft camel hair brush; DO NOT use razor blades or sharp instruments to clean optical lenses.

***Caution:*** Do not expose optical equipment to the direct rays of the sun for any length of time. Such exposure may cause the balsam cement between the lenses to deteriorate.

### Summary

To sum up general maintenance, USE OP's and OD's, paying particular attention to the sections on care and lubrication, tests, and adjustments. The information in this chapter shall in no way be taken to replace the vital information contained in Bureau of Ordnance publications, but rather to prepare you for their use. Remember, faithful routine maintenance is the life line of all fire-control gear.

## QUIZ

Fill in the word or words that BEST complete the statement or answers the question:

1. All instruments shall be inspected periodically including those in ____________.
2. Keeping electrical circuits ____________ during periods of extreme dampness will help to reduce the amount of moisture they absorb.
3. Other than reducing the friction between moving parts, much of the lubrication required for fire-control gear is for the purpose of retarding ____________.
4. Oil will deteriorate electric-wire ____________.
5. The recently developed synthetic instrument oil and grease have excellent ____________ inhibitors and antioxidants, a ____________ operating temperature, range, and an extremely ____________ rate of evaporation.
6. Major repair on fire-control equipment should never be attempted by any other than fully qualified and authorized personnel from ____________, ____________, and ____________.
7. Authority for major overhaul of fire-control instruments is obtained from the ____________.
8. The only paints recommended for fire-control instruments are __________________________.
9. After packing fire-control instruments for shipment, the container is stenciled with the words __________________________.
10. Transmission tests are taken primarily for the purpose of checking ____________ transmission systems.
11. "A" tests used for testing rangekeepers and computers are also called ____________ tests.
12. The "C" tests are used to check the performance of the __________ in a rangekeeper.
13. When "A" tests show that the average and maximum errors fail to fall within the allowable limits, the ____________ quantities are checked.
14. In taking a "C" test, the time motor is brought up to speed by turning the ____________ before turning on the time-motor switch.
15. Dynamic accuracy tests are taken with the ______________ and ______________.
16. Before gassing an optical instrument, air compressed to about 600 p. s. i. is passed through in order to thoroughly ____________ the optics and inner surfaces of the instrument.

# CHAPTER 9

## ORDNANCE ALINEMENT

Neither of your previous training courses included the original alinement of a battery that is performed while the ship is in drydock at the fitting-out yard. Nevertheless this phase of the alinement belongs in any series of training courses for Fire Control Technicians, for it is from this initial alinement that the information for subsequent alinements afloat is obtained. Therefore this chapter is devoted to the methods employed in effecting the original alinement (in drydock), and provisions for routine checking and adjustment of the alinement when at sea.

The original alinement of a battery is usually performed by yard personnel who are responsible to the ship's gunnery officer for the accuracy of the work. Consequently, if you are ordered to new construction, the gunnery officer will probably assign you to keep in touch with all phases of the alinement. You should, therefore, know what is being done, why it is being done, and what the ultimate purpose is.

It isn't necessary to discuss alinement procedures as they are applied to specific installations. Usually these procedures differ only in the method of introducing the corrections and making the adjustments; the basic principles are the same. In modern installations, the machine-gun batteries are interconnected with the larger batteries to provide for secondary director control in either direction. For that reason, these batteries must be alined also, by the procedures which will be outlined here for the guns of 5″/38 caliber and above.

## TRANSIT

The reliability of the original alinement depends upon the accuracy with which certain angles are measured with a transit. Therefore a brief description of this instrument has been included. The following discussion is by no means complete; additional study and practice will be necessary before you can expect to use a transit with any degree of accuracy. This section has been included primarily to clarify the many references to the use of the transit that are made in the remainder of this chapter.

The transit is ordinarily used by civil engineers to establish boundary lines, measure grades, run contours, and do other surveying work that requires the accurate measurement of angles. It is a precision instrument suitable for use by the Navy without modification. For this reason, these instru-

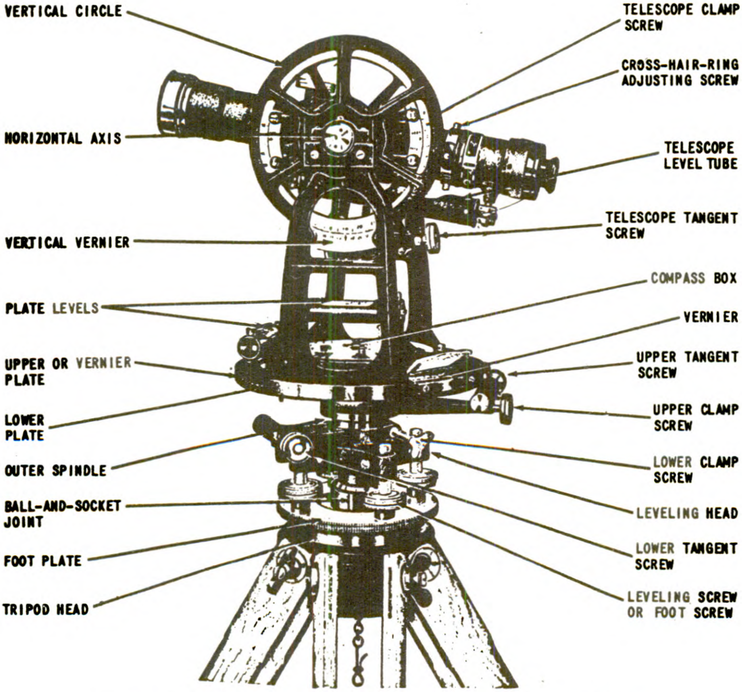


Figure 9–1.—The transit (Keuffel and Esser Model 5069F).

ments are procured through open purchase from the manufacturer and identified by the company name and model number instead of by the mark and mod designation used on equipment built expressly for the Navy. The transit shown in figures 9–1 and 9–3, for example, is the Model 5069F built by the Keuffel and Esser Company of New York. The operation of this instrument is typical of those used in naval shipyards.

Basically the transit is a boresight telescope mounted on a tripod in such a manner that the angular displacement of the line of sight (abbreviated LOS), vertically from the horizontal, or laterally from any selected point on a reference line, can be measured in degrees, minutes, and seconds of arc.

The telescope, like the boresight telescope, is of the internal focusing type. The eyepiece assembly is focused on the reticle by an eyepiece-focusing ring (see fig. 9–1), and the target is brought into focus with the reticle and eyepiece assembly by a knurled pinion knob that moves a draw tube housing the internal focusing ring. The reticle has the usual cross-line pattern plus two additional horizontal lines, one above and one below the center of the field. These two lines are called STADIA WIRES, and are used in conjunction with a STADIA ROD to measure range by the principle of similar triangles.

The vertical arc, secured to one of the trunnions, is grad-

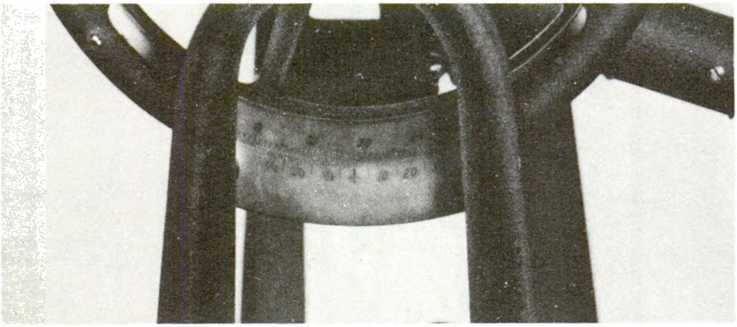


Figure 9–2.—The vertical arc and vernier.

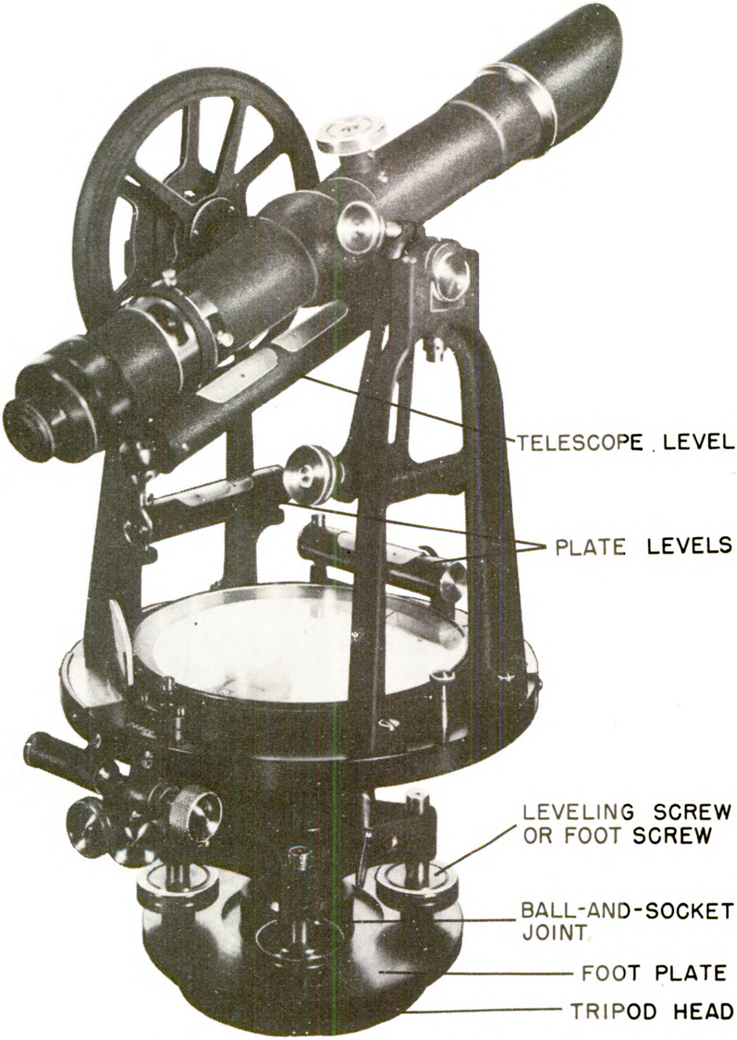


Figure 9–3.—A close-up of the elevation system.

uated through 30° in increments of 30 minutes, with every 10° numbered. The numbers run from 0 to 90 to 0 to 90 and back to 0°, with the zero graduations corresponding to the horizontal positions of the transit. The elevation of the LOS is read to individual minutes of arc on a double vernier (see fig. 9–2). To be in adjustment, a spirit level suspended from the underside of the telescope must read zero when the telescope is at zero-degree elevation and the bearing plate is horizontal. Thereafter small differences in the elevation or depression of the transit from the horizontal can be read in terms of the displacement of the bubble from the zero graduation on the glass vial. This method of measuring small angles is also used on the gunner's quadrant. (See chapter 12.)

The upper plate on which the yoke is mounted carries two spirit levels at right angles to each other in parallel horizontal planes, a magnetic compass, and a pair of double verniers 180° apart. The upper plate turns on a bearing circle that is graduated from 0° to 360° in increments of 20 minutes. Every tenth degree has two sets of numbers. Starting from zero, one set reads clockwise (CW) through 360°, the other set counterclockwise (CCW). The bearing of the LOS can be read to 30 seconds of arc on either double vernier.

The upper and lower plates of the transit rotate on a spindle that ends in a ball-and-socket joint. A leveling head and four screws are used to pivot the spindle on the joint until the transit is level, as indicated by the spirit levels on the upper plate. A plumb bob can be hung from the ball-and-socket joint to center the transit over a point (station mark).

All three movements of the transit are secured by coarse (clamp-screw) and fine (tangent-screw) adjustments.

## Transit Verniers

A few of the types of vernier scales used on transits are shown in figure 9–4. (The arrows merely indicate the exact readings given below.) While all transits are graduated to be read to single minutes of arc, there are instruments which can be read to as much as 30, 20, 10, and 5 seconds of arc.

Style A is the usual graduation of the horizontal arc of an engineer's transit and vernier. The vernier is of the double-direct reading type and is read from the center to either extreme division. The arc is graduated to 30 minutes, and the vernier has 30 divisions on either side of index *A*; therefore, the reading of the vernier is 30′/30=1 minute. The vernier in the figure reads 17° 25′ from left to right, and 342° 35′ from right to left.

Style B is used on the horizontal arc and vernier of the Keuffel and Esser Model 5069F. It is a double-direct ver-

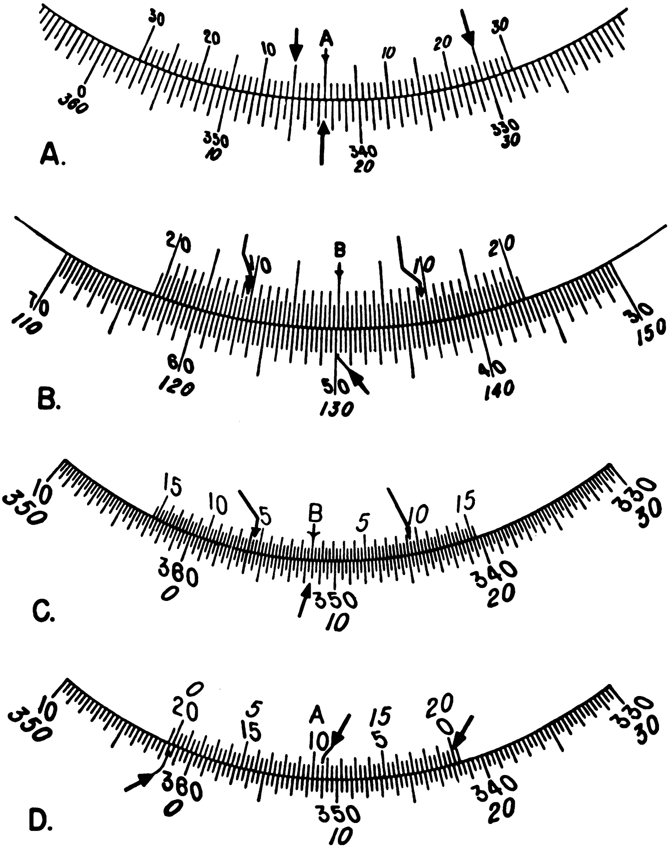


Figure 9–4.—Transit verniers.

nier. The arc is graduated to 20 minutes, and there are 40 divisions on either side of index *B*; consequently the reading of the vernier is 1200″/40=30 seconds. The figure reads 130° 9′ 30″ from left to right, and 49° 50′ 30″ from right to left.

STYLE C, also a double-direct reading vernier, can be read to 20 seconds of arc. Since the arc is graduated to 15 minutes and there are 45 divisions on either side of the center of the vernier, the reading of the vernier is 900″/45=20 seconds. The figure reads 351° 35′ 40″ from right to left, and 8° 24′ 20″ from left to right.

STYLE D represents the horizontal arc and vernier of a transit with more open divisions than the others. This is a single-direct vernier, reading from either end to the opposite extreme division, rather than from the center. The arc is graduated to 20 minutes and there are 60 divisions on the vernier. Consequently the reading of the vernier is 1200″/60=20″. The figure reads 341° 49′ 20″ from right to left, and 358° 30′ 40″ from left to right.

The vertical arc and vernier of the Model 5069F differ from Style *A* only in that the positions of the vertical arc and vernier are interchanged radially (see fig. 9–2).

## Care and Use of the Transit

When setting up the transit, place two of the legs in approximately the correct position with respect to the station mark. Move the third leg until the plumb bob is brought over the point, at the same time keeping the tripod approximately level. Keep the tripod bolt nuts just tight enough to sustain the weight of the legs when the instrument is lifted. Press the tripod shoes firmly into the ground, or block them with weights when used on a steel deck. If the plumb bob is nearly over the point, final centering on some transits may be performed by moving a shifting plate after loosening the leveling screws.

The instrument should be leveled with the greatest care. Turn the bearing plate so that each horizontal level is parallel to a pair of diagonally opposite leveling screws. Grasp a pair of opposing screws between the thumbs and forefingers and turn the screws uniformly so that the thumbs move toward or away from each other, thus tightening one screw and loosening the other. After one bubble is centered approximately, repeat with the other spirit level. It is better to center both bubbles approximately, after which one bubble and then the other may be centered exactly. Do not tighten the screws too much; you may damage the instrument and cause errors by straining the metal. After the instrument has been leveled, check the plumb bob to see that it has not moved from the reference point during the leveling process.

Always remember that the transit is a delicate instrument that requires constant care to keep it in good working condition. Make all adjustments with the greatest care; turn the adjusting screws uniformly and without strain, and clamp all motions firmly so as to secure a positive motion of the tangent screws without slipping. For best results always confine the motion of the tangent screws to the midportion of their travel.

If the transit has a magnetic compass, keep the needle locked; it is intended for field work only. Some transits do not have a magnetic compass. They are called city transits and are used in metropolitan areas where passing automobiles and steel construction work render a magnetic compass inaccurate.

If you carry the transit on your shoulder, loosen the lower clamp so that the head may revolve freely if it strikes anything. When moving through hatches, up ladders, and in other restricted places, carry the transit under your arm, with the telescope in front of your body. Protect the instrument whenever possible from sun, rain, and dust. Never use alcohol or similar liquids on the lacquered surfaces. Occasionally wipe exposed parts that collect dust and grit with a slightly oiled rag, and then rub them dry. Use only the best grade of watch oil on the transit.

When you secure, clean the transit thoroughly and rub it dry with a soft rag before returning it to the case. A sliding board holds the transit upright in the hardwood instrument case. Screw the transit on the threaded metal stud attached to the sliding board, replace the waterproof cover on the transit, and return it to its case. Always clamp the telescope so that it is not in contact with the case. Fixtures are provided in the case to hold the sunshade, wrench, screw driver, plumb bob, magnifying glass, and adjusting pins. An aluminum cap is furnished to protect the threads of the tripod head when not in use; screw the cap on the tripod head after removing the transit.

An example of the use of the transit is the typical problem of measuring the bearing and elevation of one point relative to a station mark on a horizontal base line. Place the transit over the station mark, using the plumb bob to center it accurately. Level the transit and check the level on the underside of the telescope; it must read zero when the vernier of the elevation arc reads zero and the table is level. Recheck the plumb bob; it should still be over the station mark. Now lock the upper plate (inner movement) and lower plate (outer movement) together at 0–0. Release the clamp screws on the outer movement; sight the transit approximately on a stake set up on the base line and lock the clamp screws. Center the vertical wire on one edge of the stake with the tangent screw on the outer movement. Both the train and elevation readings of the transit are 0°–0°.

Release the inner and elevation movements; sight the telescope approximately on the second point and lock the clamp screws. Adjust the tangent screws until the crosslines are on target. Read the angles in train and elevation. The train reading is the bearing of the second point relative to the position of the transit on the base line; it is read directly as either a CW or CCW bearing, depending upon the circumstances. The elevation reading is the angular elevation of the point relative to the position of the transit on the horizontal base line.

## TRANSMISSION CHECK

A thorough check of the synchro transmission system and the regulators in the guns and directors must precede the actual alinement. We shall assume, for the purpose of this discussion, that the gun barrels and trunnions are alined mechanically; thus we can go directly to the regulators.

Most indicating and regulating mechanisms can be zeroed as units, regardless of mount position. Later, when the train and elevation angles for a particular position of the mount have been measured, the response shafting to the regulators can be slipped until the dials read these known values. This procedure brings both the indicating and the regulating portions of the instruments into correspondence simultaneously with the measured position of the gun. The amount that the response shafting must be turned to effect correspondence between gun and regulator can be reduced materially, of course, by placing the gun on estimated zero train and elevation prior to zeroing the regulators.

Regulators differ so much that it is difficult to formulate specific rules for their adjustment, nor should this be necessary, since these procedures are covered in detail in the related OP's.

In general, parallax is adjusted first. The parallax dials are zeroed when the traveling nut on the parallax limit stop is at the midpoint of its travel. If the instrument is an elevation regulator, the scales in the roller-path compensator must be on zero. Then set the train or elevation angle-reader dials on zero.

Transmit zero signals to the indicating synchros in the regulators, and zero the follow-the-pointer dials. If the regulator has a parallax unit, transmit a zero signal to the *Ph* synchro and set the follow-the-pointer dial on zero.

Finally, the automatic follow-ups must be adjusted until the mount synchronizes at the zero position indicated on the angle-reader dials. Transmit a zero signal to the parallax mechanism and adjust the parallax servo to synchronize on zero. Repeat with the synchro units controlling the power drive. Adjust the synchros until the mount synchronizes in AUTOMATIC at the zero point as read on the angle-reader dials.

Thus the regulator is zeroed in INDICATING and AUTOMATIC. The instrument can be brought into correspondence with true mount position by slipping the response until the dials read the measured value.

The TRANSMISSION CHECK continues, after the zeroing of the regulators, as follows:

1. Man the telephones between the stations under test.
2. Set up the switchboard to transmit successively from:
   a. The directors to plot.
   b. Plot to the guns.
   c. The director to the guns (bypassing the computer).
   d. The stable element to the director (*L* and *Zd* in the Mk 37 system).
3. Turn the transmitters in increments of 10° from 0° to 360°. Compare the receiver readings with the transmitted values; they should check exactly. Any error of position, direction, or firmness of position should be investigated by standard synchro methods. Pay particular attention to the action of the receiver dials when coming to rest. They should stop quickly and evenly, in agreement with the transmitted signal. Sluggishness of response or long oscillations are usually an indication of mechanical trouble with the synchro receiver, and the synchro must be repaired or replaced.

## ALINING THE BATTERY IN TRAIN

The train battery alinement is designed to bring the lines of sight of all directors and the axes of all gun bores into parallelism (in the horizontal sense) at all angles of train when the ballistic and horizontal parallax corrections are zero. This alinement is performed initially by alining each element to the centerline of the ship. Each gun and director is trained through an angle relative to the centerline of the ship; the angle is measured with a transit; and the regulators are adjusted to read this angle of train.

Quite often the centerline is indiscernible because of the ship's structure, and it is necessary to use an OFFSET centerline laid off parallel to the centerline of the ship on the ground beside the drydock. Two methods (namely, direct reading and computation) are used to establish the offset centerline.

## Establishing the Offset Centerline

Direct reading is used when two points on the centerline (*A* and *B* in fig. 9–5) are visible from each other.

1. Set up a transit over *B* on the centerline. Lock the inner and outer movements together at 0–0; release the outer movement and sight on *A*.

2. Select a point on shore through the projected offset centerline—either *C* or *D*, depending on where the line is to be. Release the inner movement of the transit and sight on *C* or *D*. Read the corresponding angle (*a* or *b* in fig. 9–5).

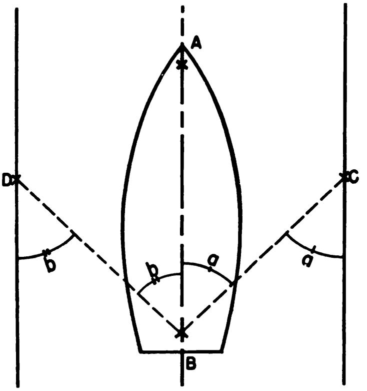


Figure 9–5.—Establishing the offset centerline by direct reading.

3. Set the transit at *C* or *D*; lock the inner and outer movements at 0–0 and sight back on *B*. Lock the outer movement, release the inner movement, and turn the transit through the angle *a* or *b*. The transit is now parallel to the centerline of the ship.

4. Mark other points on the offset centerline by setting up stakes in the LOS of the transit. If no two points on the ship's centerline are visible from each other, the following method must be employed:

    1. Select points on either side of the ship that are visible to each other and to *A* and *B* on the centerline of the ship (see fig. 9–6 points *C* and *D*).

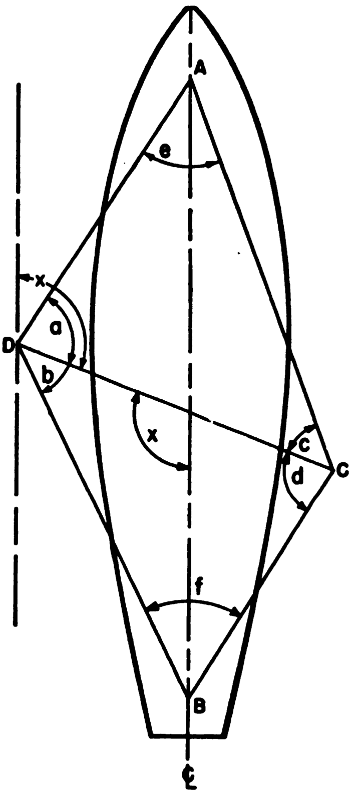


Figure 9—6.—Establishing the offset centerline by computation.

2. Set up the transit over $A$, $B$, $C$ and $D$ in turn; measure angles $a$, $b$, $c$, $d$, $e$, and $f$.
3. The value of angle $x$ may then be computed, using the data obtained in step 2.

The following formula may be used in making this computation:

$$x = \text{arc tan}\,\frac{\sin a \sin c \sin f + \sin b \sin e \sin d}{\cos a \sin c \sin f - \cos b \sin e \sin d}$$

Work sheets are available which simplify the computation of angle $x$ by logarithms.

4. Set up the transit over *D* and sight on *C*. Rotate the telescope plate through the computed angle *x*, and the telescope is then parallel to the centerline of the ship. Other points on the offset centerline may now be established as in the preceding method.

### Establishing the Center of Rotation

It is also necessary to establish the center of rotation of each battery element so that a transit may be set up over a given center of rotation to measure the true angle of train of the mount or director in question. A center of rotation may be located by using either the transit or the plumb-bob method.

In the transit method, a transit is set up (on ship or ashore) at a point from which the top of the shield or mount can be seen. If the mount is of the open type, it is necessary to build a platform on which lines to determine the center of rotation can be drawn. The platform will also be needed

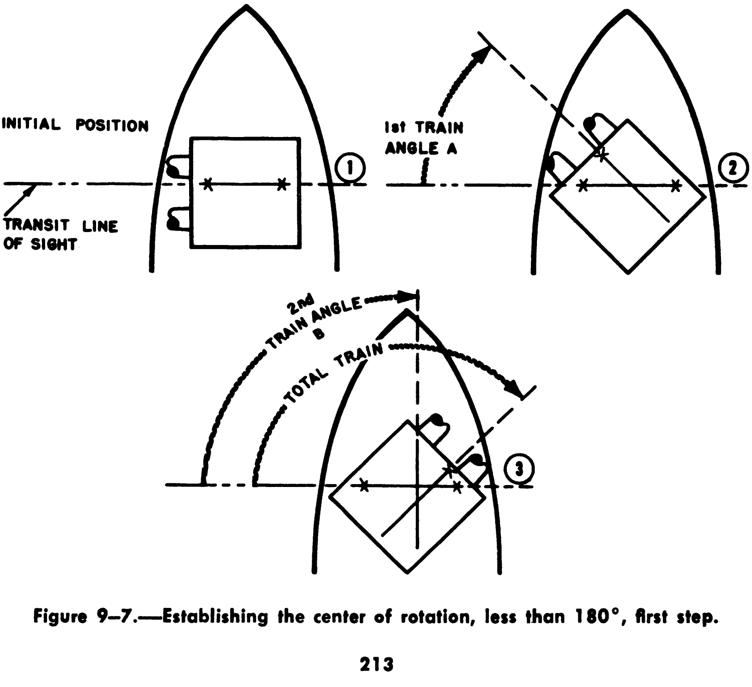


Figure 9–7.—Establishing the center of rotation, less than 180°, first step.

later to support a transit at this point. With a helper stationed on the mount, sight on its estimated center of rotation and lock all motions of the transit. On top of the mount locate two points in the transit line of sight and draw a line connecting these two points. Then train the mount through two different angles, and in each case draw a line on the mount top through the transit's line of sight. (See fig. 9–7.)

Case 1: Sum of two train angles is less than 180°. In figure 9–8, the three original lines on the mount top are designated as *ab*, *ac*, and *bc*. Draw the bisector of the angle formed by *ab* and *bc*. In the figure this is *ob*, the bisector of angle *cba*. Next draw the bisector of the angle formed by *bc* and *ac*. In the figure this bisector is *co*. Finally, draw the bisector of the angle formed by *ca* and *ba*. In the figure this bisector is *ao*. The intersection of these three bisectors is the center of rotation, *o*.

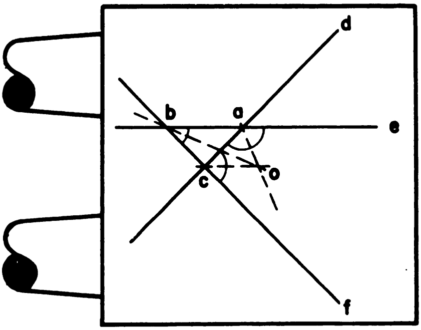


Figure 9–8.—Establishing center of rotation, when total train angle is less than 180°, second step.

Case 2: Sum of the two train angles is greater than 180°. As shown in figure 9–9, the three original lines are labeled as in case 1. Note also that the intersection of the bisectors of each of the interior angles of the triangle is the center of rotation, *o*. In the figure these bisectors are *oa*, *ob*, and *oc*.

The plumb-bob method can be used if a structure not attached to the mount is available over the mount. Suspend a plumb bob from this structure so that it hangs close to the

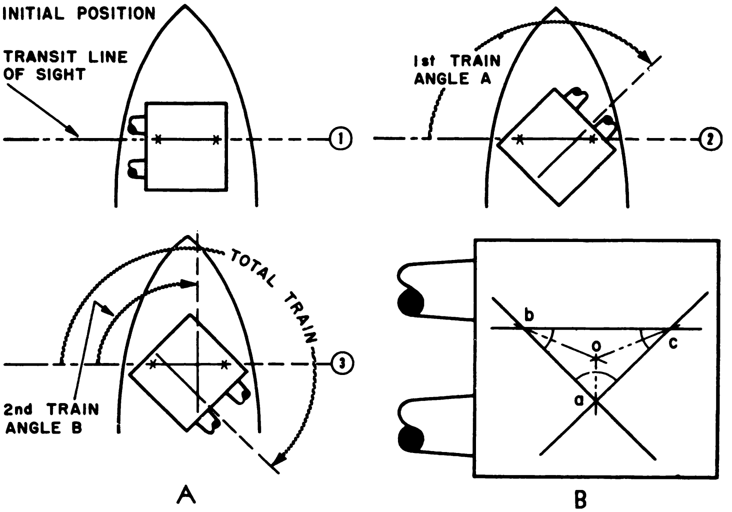


Figure 9–9.—Establishing center of rotation when total train angle is greater than 180°.

estimated center of rotation. As the mount is trained the plumb bob will describe a circle, the center of which is the actual center of rotation.

After a center of rotation has been determined, it should be checked by sighting from a transit to assure that this calculated center does not move out of the transit line of sight when the mount is trained. The center of rotation should then be permanently marked for future use.

### Establishing Zero Train—Director

The first step in effecting actual alinement in train is the establishment of zero train; that is, setting the train dials of each element so that when these dials read zero train, the line of sight or bore axis of the element in question is parallel to the centerline of the ship and pointing forward. Zero train of a director is established as follows:

1. Select some point on shore (*M* in fig. 9–10) from which the director and some point (*C*) on the offset centerline can

both be seen. This point (*M*) is the reference point, and will be used for zeroing all elements that can be seen from it.

2. Set up a transit over *C*, lock telescope at zero on azimuth scale, and sight forward along the offset centerline at some point (*N*). Lock the azimuth plate movement, release the telescope plate, and sight on *M*. Read and record the angle (*a*).

3. Set up a transit over *M*, lock the telescope at zero on azimuth scale, and sight back at *C*. Lock the azimuth plate, release the telescope plate, and sight on the center of rotation of the director (previously established and marked). Read and record this angle (*b*).

4. Train the director until the reference telescope (usually the pointer's), which in this discussion is considered as being located on the centerline of the director and properly alined with all other parts of the director assembly, is sighted di-

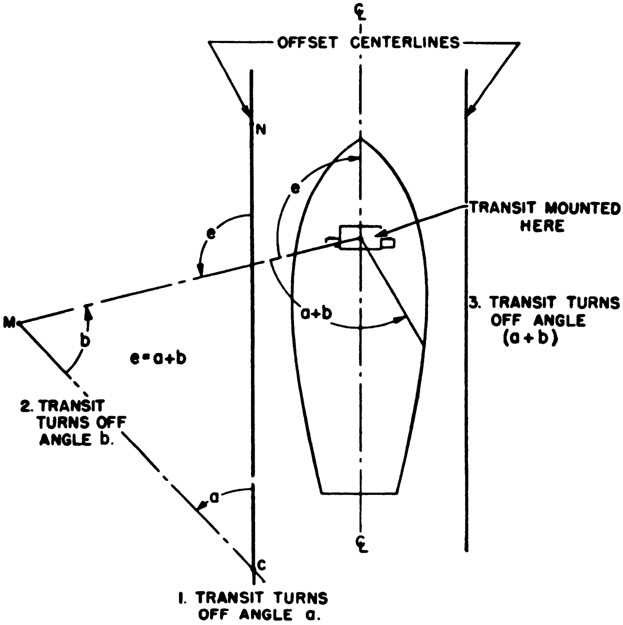

℄
OFFSET CENTERLINES
N
e
e
TRANSIT MOUNTED HERE
M
b
e=a+b
a+b
3. TRANSIT TURNS OFF ANGLE (a+b)
2. TRANSIT TURNS OFF ANGLE b.
a
C
℄
I. TRANSIT TURNS OFF ANGLE a.

Figure 9–10.—Establishing zero train of a director.

rectly on *M*. Make sure that parallax is not present in the telescope, and also that no horizontal parallax is being introduced into the director dials by its parallax mechanism.

5. Set up a transit over the director's center of rotation, lock telescope at zero on azimuth scale, sight back at point *M*, and lock azimuth plate. Now both the transit and the reference telescope are sighted on *M*.

6. Study of figure 9–10 shows that the director and the transit are trained from the true fore-and-aft direction by the angle *e*. This angle (*e*) is equal to angle *a* plus angle *b*.

7. Release the telescope plate of the transit, and turn it aft until it reads the angle *e* (or $a+b$). Lock the telescope plate.

8. Now train the director forward until the transit is again on point *M*. Obviously, the director has been trained forward through angle *e*, and now is exactly parallel with the centerline of the ship. Adjust the dials until they read zero train at this point, and adjust the transmitters so that they transmit zero train.

For purposes of checking director zero train at sea, a bench mark and a bench-mark reading are established. The bench mark usually is a small brass plate with crosslines etched on it. This plate is welded to a secure part of the ship within vision of the director sights. After zero director train has been established and the dials set, train the director and put the crosswires of the pointer's telescope on the bench mark, and read the train angle-reader dials. This is the bench-mark reading which should be recorded. The same telescope must be used for obtaining all settings and readings. On multiple director installations the parallax corrector must be set at infinity—the point at which no parallax correction is entered into the train dials.

### Establishing Zero Train—Turrets

To establish zero train of a gun mount or turret, the guns (not the sights) are sighted on reference point *M*. (See fig. 9–10.) To do this, a boresight telescope is put in the barrel of a single mount or in the middle barrel of a triple mount and sighted on *M*. The boresight telescope must have its line of sight at the centerline of the bore. Then a transit is set up over the center of rotation, and sighted on *M* to establish zero. The transit is offset the sum of *a* and *b* away from the bow, and is secured. The mount is then trained until the transit is again sighted on *M*. This is zero train, and the dials may be set at 0° (180° in the case of the after guns).

When a two-gun turret is at zero train, both gun bores should be parallel (within practical limits) to the centerline of the ship. Therefore, a somewhat different procedure is necessary to establish zero train, because both guns are offset from the center of the turret. The steps are as follows. Set up a transit over the turret's center of rotation and install a boresight telescope in each gun. Train the turret until gun *A* is sighted on reference *M*. Establish zero for the transit by training it on reference *M*. (See fig. 9–11 (A).) Now train the turret until gun *B* is on *M*, sight the transit on *M* and read the angle *d* turned off by the transit. (See fig.

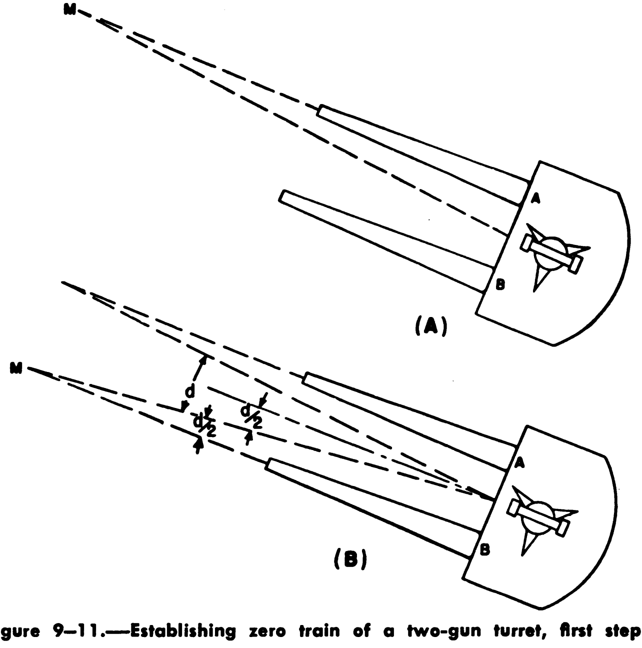


Figure 9–11.—Establishing zero train of a two-gun turret, first step.

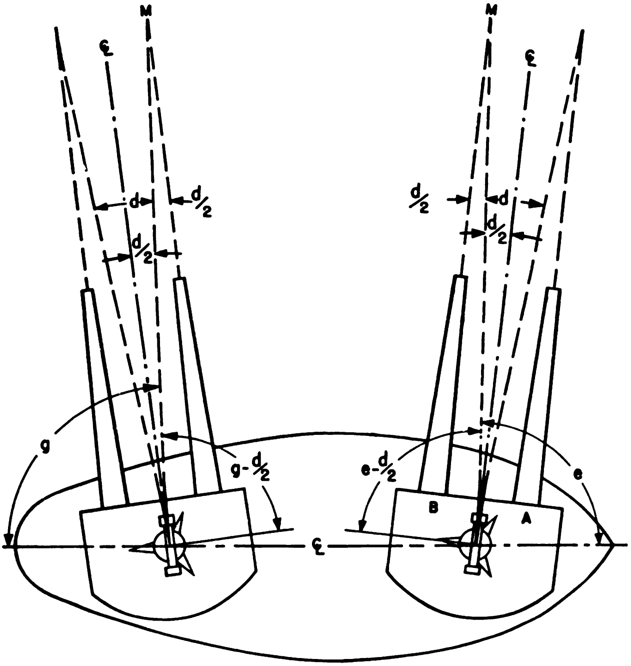


Figure 9–12.—Establishing zero train of a two-gun turret, second step.

9–11 (B).) Then $\frac{d}{2}$ is the angle at *M* formed by the lines of sight of the transit and gun *B*. Starting with the transit and gun *B* trained on *M*, turn the transit to the left through the angle equal to $e-\frac{d}{2}$. (See fig. 9–12.) The forward gun *A* could be used, but the angle in this case would be $e+\frac{d}{2}$. Then train the turret until the transit is again sighted on *M*, and the turret will be at zero train. The dials should then read zero. Be sure that there is no parallax input to the turret and dials.

In the case of the after turret (fig. 9–12) the angle turned toward the bow is $g-\frac{d}{2}$; then the turret is trained aft until the transit is on *M* again. Dials should read 180°.

The transit method is the most accurate means of measuring the tram reading for each mount.

1. The last step in the zero train sequence left the mount on zero and the transit LOS on *M*; the dials read zero train. Now insert the tram bar between the tram blocks (one on the carriage and one on the stand) and train the gun until the zero marks on the telescopic portions of the tram bar are alined.

2. Train the transit back to *M* and read angle *f* (fig. 9–13). Angle *f* has been greatly exaggerated—normally the tram position of the mount is within a few degrees of zero train.

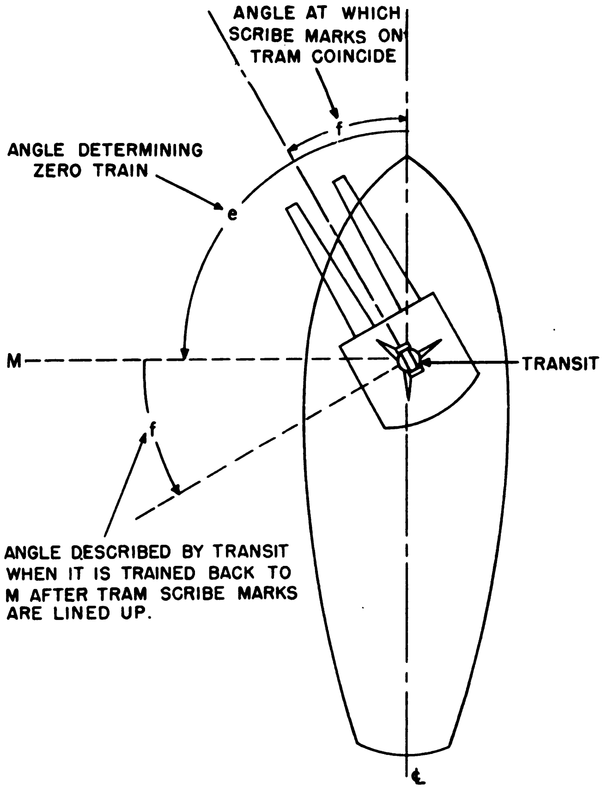

ANGLE AT WHICH SCRIBE MARKS ON TRAM COINCIDE
f
ANGLE DETERMINING ZERO TRAIN
e
M
TRANSIT
f
ANGLE DESCRIBED BY TRANSIT WHEN IT IS TRAINED BACK TO M AFTER TRAM SCRIBE MARKS ARE LINED UP.
℄

Figure 9–13.—Measuring the train angle with the tram in position.

3. If the mount is trained CW from zero to the tram point, angle *f* is the tram reading. If the mount is trained CCW from zero as shown in figure 9–13 the actual dial reading is $360° - f$.

4. Engrave the tram reading for the mount on the inner side of the brass cover plates that protect the tram blocks. Pack the space under the cover plates with a heavy grease before replacing the covers.

### The Dial Accuracy Check

The alinement of the battery in train concludes with a check on the accuracy of the dials. This check must always be performed, and as usual, parallax must be on zero.

1. Select as a target a distant building or smokestack with a good vertical edge.
2. Set up the transit over the center of rotation.
3. Train the director or mount to zero train and sight the transit on the target. Lock the inner and outer movements together at 0–0.
4. Train the mount 10° as read on the angle-reader dials. ALWAYS COME UP TO BUT NEVER PASS THE 10° MARK ON THE DIAL.
5. Swing the transit back on the target; read and record the angle turned off by the transit.
6. Train the mount an additional 10° to the 20° mark on the angle-reader dials.
7. Turn the transit back to the target and read the angle turned off by the transit. This angle should be 10° also, and the total transit reading 20°.
8. Continue this procedure throughout the limits of director or gun mount train, and repeat in the opposite direction to check for lost motion.

## ALINEMENT IN ELEVATION

The battery is alined in elevation after it has been alined in train. The battery must be adjusted so that at any angle of train and elevation the lines of sight of the directors and guns, and the bore axes of the guns will all be elevated at exactly the same angle above a common reference plane, provided the dials are matched and the vertical parallax and ballistic corrections are on zero. All elements must be alined mechanically and the transmission check must have been completed satisfactorily prior to undertaking the elevation alinement.

There is often an appreciable change in the shape of a vessel between the drydock and afloat conditions; thus it is not always possible to effect a final operating alinement afloat on the basis of the data obtained in drydock. The battery may have to be realined when the ship is waterborne to compensate for the changes in the shape of the ship and the resultant shift in the relative positions of the roller paths. This preliminary work must be conducted, however, to select a reference roller path and make the initial corrective settings of the roller-path compensators.

The most important phase of the elevation alinement is the procurement and interpretation of the roller-path data. This phase of the alinement has been discussed under the second class qualifications, but for convenience a few of the fundamentals are reviewed here.

## Taking Roller-Path Data

In all modern installations it is assumed that the roller paths of the individual elements are true planes, or at least so close to true planes that distortion is unimportant and not measurable. Thus our concern is with the inclinations of the several true planes containing the roller paths to some fixed reference plane. If the ship is waterborne, this reference plane is the reference plane of the battery; but if the ship is drydocked, the reference plane is the horizontal measured by a spirit level.

Assume that the shaded plane in figure 9–14 represents the true inclined plane containing the roller path of a gun mount or director. The inclination of this plane to the reference plane is defined by the bearing of the high point (angle *Br*) relative to the centerline of the ship, and the inclination of the high point (angle *T*). Ordinarily the

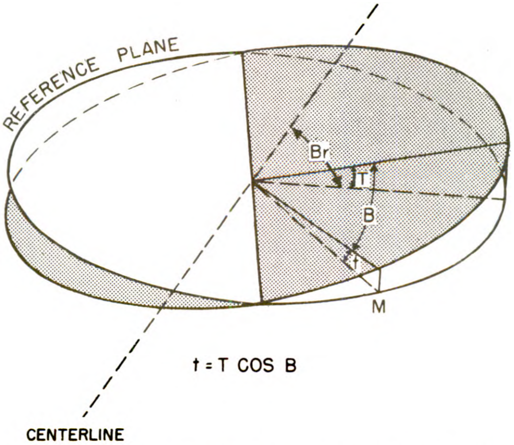


**Figure 9–14.—Relationship between the horizontal and a tilted plane.**

bearing and inclination of the high point cannot be found directly, but must be found through interpretation of a series of readings known as roller-path data.

In figure 9–14, the angle of inclination $t$ at any point $M$ is equal to angle $T$ multiplied by the cosine of angle $B$ (the train angle between the high point and the point under consideration). Thus a plot of $T$ cos $B$ will vary sinusoidally, with some of the readings positive and some negative. If the plot does not vary sinusoidally (mistakes in roller-path data excepted), it is evident that the roller path has become distorted and is no longer a true plane.

The procedure for taking roller-path data is:

1. Secure the quadrant to a smooth surface on the gun or director, with the pivot forward and the reference line of the quadrant parallel to the bore-axis of the gun, or the LOS of the director.

2. Elevate the gun to some convenient angle of elevation that will make all the readings positive. The difference in readings is important; the elevation of the gun is immaterial. The forward end of the quadrant must be shimmed to accomplish the same result in a director.

3. Train the gun or director to zero; level the bubble and

read the quadrant. Repeat every 10° or 15° throughout the entire training limits of the element—if possible, through 360°. Record the inclination and train angle in each case.

### Interpretation of Roller-Path Data

The purpose of the roller-path data is to determine the relationship between the roller path and the horizontal plane. Knowing this relationship, we can calculate the relationship between the roller paths of the various elements.

The problem, then, is to find *T* and *Br* for each roller path. Three graphic methods are available for this determination. They are: the sine-curve method, the 180° method, and the 60° method. Both the 60° method and 180° method are preferable to the sine-curve method, which is used only for the interpretation of roller-path data taken afloat.

### Choosing the Reference Plane

Since the purpose of battery alinement in elevation is to cause the various elements to elevate equally above a reference plane, it is necessary to choose some plane as that reference.

The reference plane generally chosen is an actual plane on the ship; that is, it is the roller-path plane of one battery element. The plane is so chosen that the inclination between it and the roller paths of the other elements is as small as possible. On destroyers there is only one large director, and it is not equipped with a roller-path tilt compensator, while each of the 5-inch mounts has a compensator. The plane of the director roller path must therefore be the reference plane of the battery. If all the guns and the director were installed simultaneously, with no special consideration given to roller-path inclination (other than the usual attempt to install the elements as nearly horizontal as possible), the plane of the director roller path might vary so much with respect to one or more of the guns that it would be unsuitable as a reference plane. Therefore, destroyer guns are installed first. Then the roller-path data for each gun are taken, and the mean of all the inclinations is computed. The director foundation is machined so that its bearing surface will be as nearly parallel to this mean plane as possible.

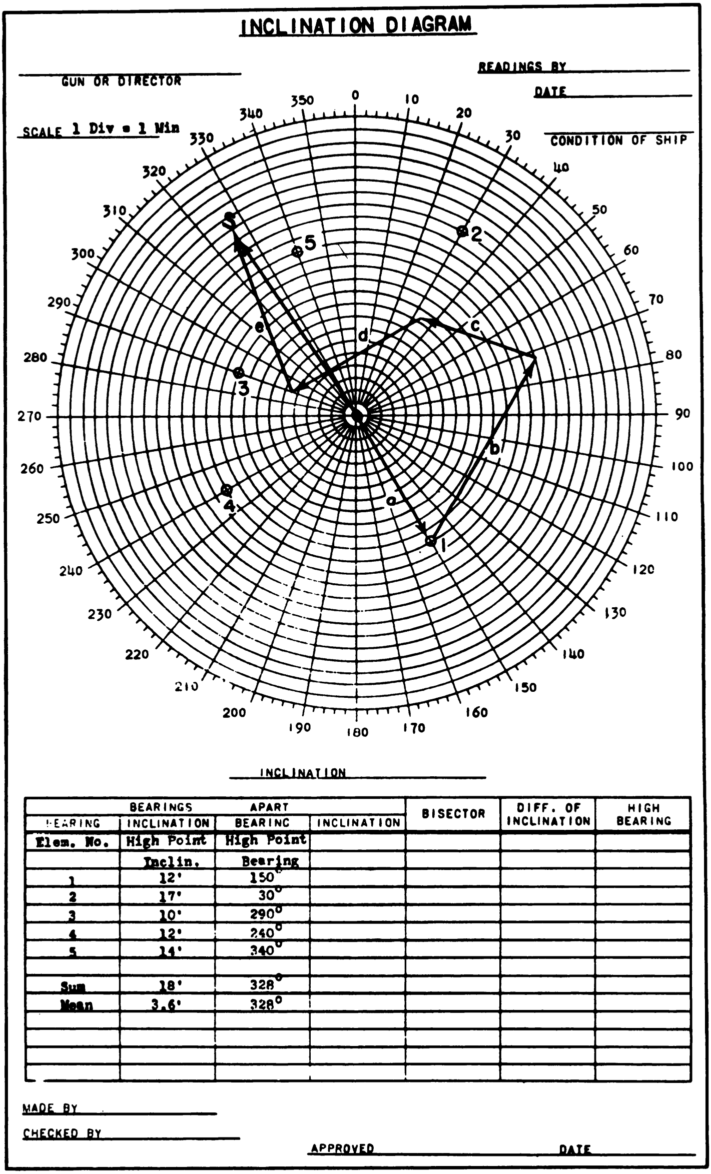
On larger ships having several directors, each director is equipped with a roller-path tilt compensator. Therefore the roller path of any battery element may be chosen as a reference. In this case all the elements are installed before any roller-path data are taken. The installing crew, of course, attempts to make all the roller paths parallel. After installation, roller-path data are taken for all the elements. The mean plane of the entire battery, guns and directors, is computed; and the roller path whose inclination is closest to the mean plane is taken as the reference plane.

On modern ships, the roller paths of the individual elements are machined very close to parallel, and almost any of them could be used as the reference plane. Present specifications require that the roller paths of the large elements be within 15 minutes of one another. In addition, the roller paths of the 40-mm and the 3″/50 gun mounts and their directors must be within 6 minutes of the reference plane of the dual-purpose battery, so that interconnection may be accomplished.

The selection of the reference roller path is affected also by the obvious necessity of picking a roller path whose inclination will be unaffected by the waterborne changes in the ship's structure. This comparatively stable roller path then becomes the mean plane, and the bearing and inclination of each of the remaining roller paths are referred to this mean plane.

### Computing the Mean Plane

Thus it becomes necessary to determine how much and at what bearing each of the elements is tilted with respect to this mean plane or reference. The radial or polar coordinate diagram is used for this purpose. The process, fundamentally, involves shifting the origin of the graph so that it lies at the reference point, or what amounts to the same thing—moving all the points without disturbing their



# INCLINATION DIAGRAM

GUN OR DIRECTOR ____________

READINGS BY ____________

DATE ____________

SCALE 1 Div = 1 Min

CONDITION OF SHIP ____________

INCLINATION ____________

| BEARINGS | | APART | | BISECTOR | DIFF. OF INCLINATION | HIGH BEARING |
|---|---|---|---|---|---|---|
| BEARING | INCLINATION | BEARING | INCLINATION | | | |
| Elem. No. | High Point Inclin. | High Point Bearing | | | | |
| 1 | 12' | 150° | | | | |
| 2 | 17' | 30° | | | | |
| 3 | 10' | 290° | | | | |
| 4 | 12' | 240° | | | | |
| 5 | 14' | 340° | | | | |
| | | | | | | |
| Sum | 18' | 328° | | | | |
| Mean | 3.6' | 328° | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

MADE BY ____________

CHECKED BY ____________

APPROVED ____________ DATE ____________

Figure 9-15.—Computing the mean plane.

relationship until the reference point lies on the origin of the graph.

In figure 9–15 there are five elements whose bearings and inclinations are to be averaged. The bearing and inclination of each of their high points are indicated in the table below the graph. These are plotted on the radial diagram by choosing the radius representing the bearing of the high point and measure radially along this bearing from the center a distance representing the inclination at that bearing. The points thus obtained are shown on the figure as small circles, numbered from 1 to 5.

The mean inclination is the vectorial sum of the various inclinations divided by the total number of elements. The method follows:

1. Draw a line from the center of the graph to point one on figure 9–15. This is the vector representing the inclination of element No. 1. Likewise, a line drawn from the center of the graph to any of the numbered points is the vector representing the point's inclination. These are the vectors which must be added.
2. From point 1 draw a line parallel and equal in length to a vector drawn from the origin to point 2. This line is shown in figure 9–15 as *b*.
3. From the end of line *b*, draw a line parallel and equal in length to a vector which would represent element No. 3. This is line *c*. Repeat the process for each element, starting the line for each element at the end of the preceding line.
4. The end of the last line, the point *S*, represents the vectorial sum of inclinations. The line from the center of the graph to this point is its corresponding vector, and its value may be read from the graph. Thus in the example, the bearing is approximately 328°, and the inclination is 18 minutes.
5. The mean is the total inclination (18 minutes) divided by 5 (the number of elements), or an inclination of 3.6 minutes at a bearing of 328°.

## Referring Elements to Reference Plane

Once the mean roller path has been computed, the reference plane is chosen. As explained previously, on destroyers the

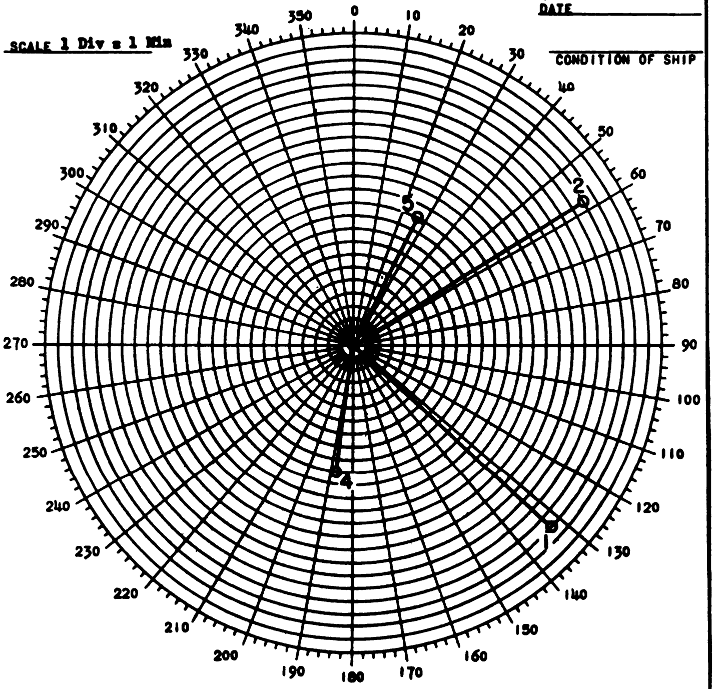
GUN OR DIRECTOR ____________________

READINGS BY ____________________

DATE ____________________

SCALE 1 Div = 1 Min

CONDITION OF SHIP ____________________



INCLINATION

| BEARINGS APART | | | | BISECTOR | DIFF. OF INCLINATION | HIGH BEARING |
|---|---|---|---|---|---|---|
| BEARING | INCLINATION | BEARING | INCLINATION | | | |
| | | | | | | |
| Reference - | No. 3 | | | | | |
| | | | | | | |
| Inclination with Respect to Reference | | | | | | |
| | | | | | | |
| Elem. No. | Bearing | Incl. | | | | |
| 1 | 132° | 21' | | | | |
| 2 | 58° | 21' | | | | |
| 3 | 0 | 0 | | | | |
| 4 | 188° | 10' | | | | |
| 5 | 26° | 11' | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

MADE BY ____________________

CHECKED BY ____________________

APPROVED ____________________ DATE ____________________

Figure 9–16.—Inclination with respect to one element.

reference is the roller path of the director. After the director has been installed as nearly as possible parallel to the mean roller path of the other elements, roller-path data for the director are taken and the bearing and inclination computed. With larger ships, of course, it is necessary to choose only one of the elements as the reference.

After the reference has been chosen, and its tilt becomes known, the other elements must be referred to this reference; that is, it is necessary to determine how much and at what bearing each remaining element is tilted with respect to this reference.

The polar coordinate diagram is used also for this purpose. The process consists of shifting the origin of the graph so that it lies at the reference point. This is equivalent to moving the points representing all the elements, without disturbing their relationship, until the reference point lies on the origin of the graph. Figure 9–16 shows the points from the preceding graph (fig. 9–15) transferred so that element No. 3 is the reference.

The inclination of any element to this reference may be read from the new graph. For example (in fig. 9–16) element No. 1 is inclined to element No. 3 by 21 minutes at a bearing of 132°.

The inclination of each element with respect to the reference is read on the new graph and recorded.

### Elevation Bench Mark for the Director

The elevation bench mark for the director is established as a reference for checking the director sights and dials at sea.

### Shore Transit Method

1. Train the director to either the high or the low point of the roller path as secured from the roller-path data. This point is selected so that the true tilt of the director may be read easily from the roller-path data.
2. Depress the LOS of the director until the ground alongside the drydock is visible through the pointer's scope. Mark

a point on the ground in the LOS. This will be the station mark for the transit.

3. Set the transit over the station mark; level the table, and check the bubble on the telescope level. The spirit level on the underside of the telescope should be on zero when the elevation vernier reads zero and the table is level.

4. Illuminate the pointer's telescope from inside the director with a flashlight, and sight into this telescope from the transit.

5. Be sure that the vertical parallax correctors are inoperative or that parallax range is set at infinity. The roller-path inclination compensator must be set at 0° inclination.

6. Read angle *a* on the transit (see fig. 9–17).

7. Read angle *b* from the roller-path data.

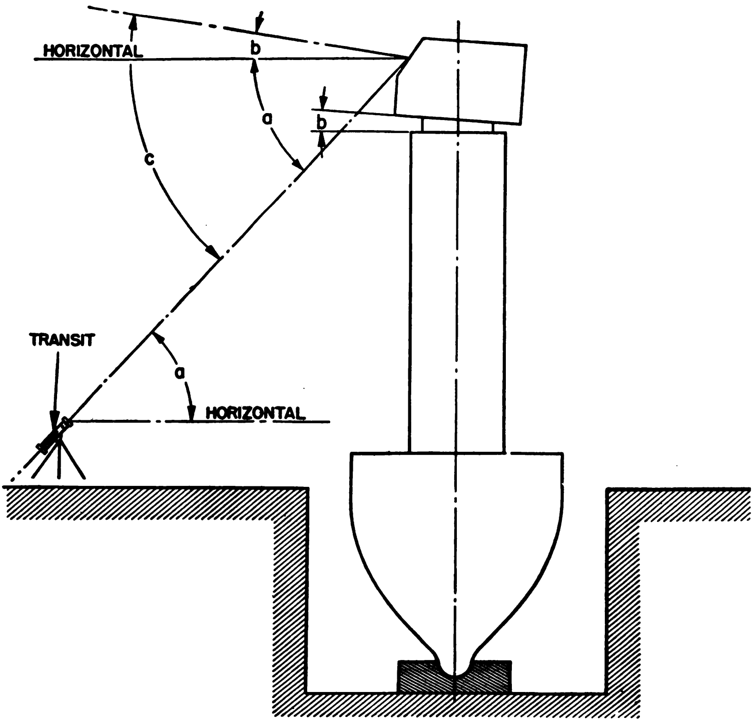


Figure 9–17.—Establishing elevation bench marks.

8. If the director is trained to the high point of the roller path, angle *c* is the amount the LOS has been depressed from a line parallel to the roller path to sight on the transit. This angle is equal to *a* plus *b*. By setting the elevation dials of the director to read angle *c*, the LOS will be parallel to the roller path at 0° elevation, which is the condition desired.

9. Adjust the elevation dials and regulators to read and transmit angle *c* when the director LOS is sighted on the transit. The elevation of the director is now measured from the director's roller path.

10. Train the director around and depress the pointer's scope to the bench mark. Read and record the bench-mark depression. Remember that the roller-path compensator is on zero.

### Deck Transit Method

The deck transit method is an alternate method of establishing the elevation bench mark that is useful when the director LOS can be depressed sufficiently to see the deck. The following procedure is used:

1. Train the director to a point where the deck is visible through the telescopes. This is 0° train on a destroyer, but on larger ships it will vary with the type of ship and the location of the director.

2. Depress the LOS of the pointer's telescope to the approximate spot selected for the location of the bench mark.

3. Set a transit over a station mark in the director LOS and sight back into the pointer's telescope, which should be illuminated with a flashlight. The transit may have to be adjusted fore and aft to aline the telescope with LOS of the director. Be sure the transit was leveled properly prior to reading the elevation of the transit; this is angle *b* (in fig. 9–18).

4. From the roller-path data compute the roller-path inclination at the particular angle of director train. This is angle *a* (in fig. 9–18).

5. Set the director elevation dials to read the difference of angles *a* and *b*. Reading (*b*—*a*).

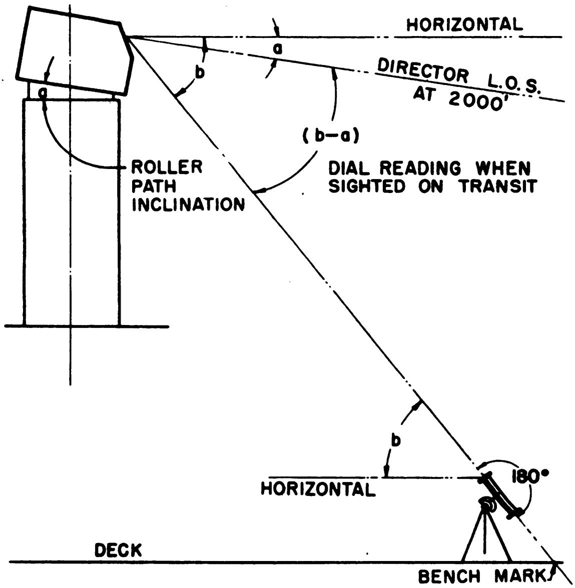


Figure 9–18.—Another method of establishing the bench mark.

6. Lock the train movements of the transit securely, and turn the transit telescope on its trunnions through 180°. The crosslines of the proposed bench mark must intersect at the point on deck in the LOS of the transit.

### Establishing the Elevation Tram Marks for the Guns

We have seen that the purpose of the elevation battery alinement is to cause all the guns to elevate equally above a common reference plane, provided their dials are matched. Thus it is necessary that the elevation dials in each gun and director read the elevation of that element above its own roller path. This elevation is then corrected by the roller-path compensator so that the gun elevates equally with the others above a common reference plane.

To ensure, therefore, that the elevation dials of the guns read the true elevation above their own roller paths, the dials of each gun must be set to the proper position while the ship is in drydock. This may be accomplished by any one of the following three methods:

1. Install a boresight telescope in the gun and proceed in exactly the same way as was used for setting the director dials, using a transit mounted on shore.
2. Boresight the gun; set sight angle and sight deflection on zero, and use the sights instead of the boresight telescope, proceeding as with the director.
3. Make use of the gunner's quadrant, which is perhaps the most accurate, as explained below.

Train the gun to any angle of train at which one of the readings for the roller-path data was taken. Refer to the roller-path data and obtain the roller-path inclination at this point.

Set up a gunner's quadrant on the gun, as when taking roller-path data. Adjust the quadrant to zero before using.

Elevate the gun to any convenient angle of elevation, and read the quadrant. Refer now to figure 9–19, part *A*; it is evident that the quadrant has measured the angle *A*

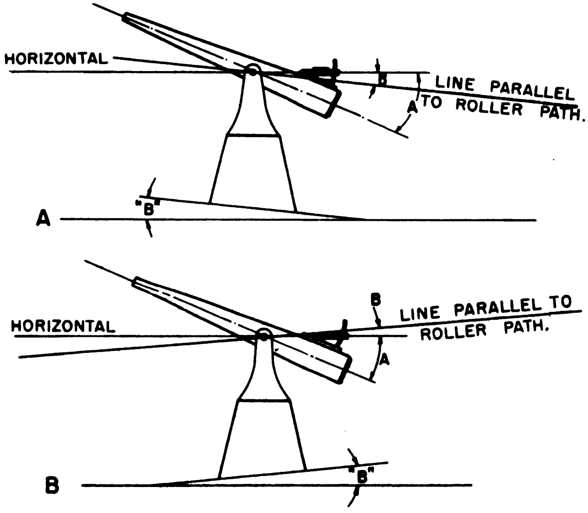


**Figure 9–19.—Setting the gun elevation dials and establishing the elevation tram marks.**

between the gun bore and the true horizontal. But the gun roller path is inclined to the horizontal by the angle *B* as obtained from the roller-path data; therefore the true angle of elevation above the roller path is *A* minus *B*. If the gun is trained to a point where the roller path is inclined below the horizontal (fig. 9–19, part *B*), the angle will be *A* plus *B*.

Set the dials to read this value of *A* plus or minus *B*. After the dials are adjusted, insert the tram between the tram blocks, and elevate the gun until the index lines on the tram are alined. Read the elevation angle either from the dials or from the gunner's quadrant (if the gunner's quadrant is used, correct for roller-path tilt as above) and record this angle as the tram reading. This angle may be used at any future time to check the dials—it is necessary, of course, if the roller-path compensator is not set on zero, to train the gun 90° from the high point before tramming and reading the elevation dials.

### Plotting-Room Director or Stable Element

The stable element, stable vertical, or plotting-room director must be alined so that the plane of rotation of the sensitive element is parallel to the reference plane of the battery. The sensitive element is trained in accordance with director train, and not in accordance with relative bearing in the horizontal plane. Its roller path, therefore, must be parallel to the reference plane, so that director train will produce the correct train of the stable-element gimbals. Since these instruments are not equipped with roller-path compensators, they must be alined by shimming.

Two methods are available for alining the stable element with the reference plane. Method one consists of taking roller-path data on the stable element; computing the tilt of the element with respect to the reference plane; and, finally, computing the amount of shimming required under each leg of the instrument to aline it with the reference plane. Method one is used on the stable elements Mk 5, Mk 6 and Mods, and the Gun Director Mk 41 (stable vertical). The roller-path data are taken with a Mk 7 gunner's quadrant.

Method two, now largely obsolete, was used with the older stable elements and plotting-room directors. The case of the instrument was alined on two bearings, 90° apart, so that its inclination with respect to the horizontal was equal to that of the reference plane.

### Method One

1. The cross-level gimbal of the sensitive element is mounted in two gimbal-mounting brackets. One of these has a large brass gear mounted on the gimbal shaft projecting through the gimbal-mounting bracket. The other bracket has no gear and is easily reached—train the sensitive element until this bracket is opposite the large rear door of the stable-element case. Open the door and remove the terminal block from the bracket; allow the terminal block to hang by its wire.

2. Every naval shipyard should have a steel block, 9 inches by 1 inch by ½ inch, that can be mounted on the bracket in place of the terminal block. Secure this block to the bracket with the two screws that previously held the terminal block in place.

3. Place the drum-type gunner's quadrant on the block with the pivot end to your right as you look into the case through the rear door. This is to be observed, regardless of the position of the stable element with respect to the ship's centerline. When the quadrant is mounted in this position and leveled, it reads the inclination at a bearing 90° less than the bearing of the LOS shown on the director-train dials of the stable element. Shim up the pivot end of the quadrant so that all readings are positive. Clamp the quadrant on the block with two small clamps.

4. Train the quadrant to various bearings; level, and read the quadrant at each bearing. The bearing corresponding to a given quadrant reading will be 90° less than the bearing shown on the bearing dials. (When the bearing is such that the quadrant is inaccessible from any of the doors, it will be necessary to train the gimbal ring until the quadrant can be

adjusted, then train back to the proper bearing and observe whether the bubble is centered.)

5. Compute the bearing and inclination of the high point from the roller-path data.

6. Plot this bearing and inclination on the radial diagram previously used for plotting the inclinations of the other elements of the battery (see fig. 9–15). Then transfer this plot to the diagram on which the inclinations or each element with respect to the reference were computed (see fig. 9–16). Read the bearing and inclination of the stable-element roller path with respect to the reference from this graph.

7. On a plain sheet of paper, draw a vertical line representing the ship's centerline (see fig. 9–20). Draw a triangle, *ABC*, representing the three mounting legs of the stable element drawn to scale and in their correct relationship to the centerline of the ship. In the example the scale is ⅛-inch equals 1 inch, and the legs are drawn so that the single leg is to starboard. This is the position of the stable element on a small destroyer, where it is abaft the computer.

8. From any point *O* on the line representing the ship's centerline, draw a line *OZ* at the bearing of the high point of the stable element's roller path. In this example, we shall assume that the bearing of the high point is 135°, and its inclination at that bearing is 15 minutes.

9. Starting at any point on line *OZ* a considerable distance from the centerline, come in along the line with a series of lines perpendicular to *OZ*. Two of these are shown, unlettered, in figure 9–20. Continue drawing these lines until the triangle is reached.

10. When the triangle is reached, draw a perpendicular from the first vertex of the triangle which is reached. In this case it is *B*, and the perpendicular drawn is *BX*.

11. Drop the perpendiculars from the other two vertices of the triangle to the line *BX*. These are the lines *AD* and *CE*.

12. Measure the length of these two lines *AD* and *CE*; and by use of the scale (⅛-inch = 1 inch), convert these lengths to the actual length represented. In the example, the length

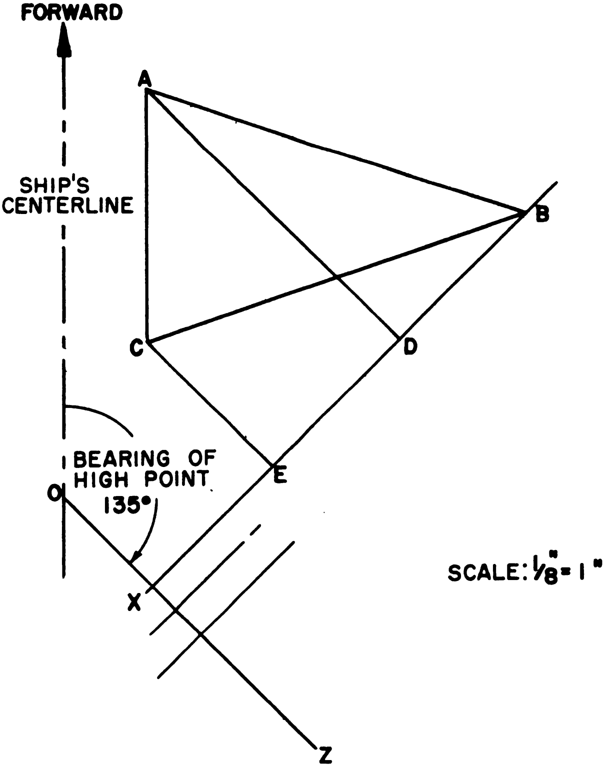


Figure 9–20.—Computing correction for stable element.

represented by *AD* is 25½ inches, and that represented by *CE* is 12½ inches.

13. To compute the amount of shimming necessary for each leg, substitute each of these two lengths in the formula:

$$S=0.0003LT$$

where $S$ is the amount of shimming, in inches needed under the leg from which the line was drawn; $L$ is the length in inches represented by the line; and $T$ is the tilt of the stable-element roller path at its high point in minutes. From this formula, in our example, *A* must be shimmed upward 0.115 inch and *B*, 0.056 inch.

14. Using the value of $S$ obtained by the formula, shim

the proper amount under each of the two legs. Note that, in any case, one leg needs no shimming.

15. Repeat the taking of roller-path data, and compute the new tilt with respect to the reference plane. It should, of course, now have no tilt with respect to the reference plane. If the tilt is greater than two minutes, the calculation and shimming must be repeated.

### Method Two

This method must be used when the stable element is so designed that a gunner's quadrant cannot be placed on the rotating part of the element. It must be used also on the Mk 6 type when the small drum-type quadrant is not available. Method one, however, is more accurate and should be used whenever possible.

Method two consists of bringing the top of the stable-element case into parallelism with the reference plane. Its accuracy, therefore, depends upon the accuracy with which the roller path of the element was alined with the top of the case during manufacture.

The alinement is performed with two gunner's quadrants placed at right angles to each other on the top of the instrument case, one parallel to the ship's centerline and one athwartships. When the stable element is correctly alined, the fore-and-aft quadrant should read the roller-path inclination of the director when the director is trained to 90° or 270°, depending upon which of the two readings is positive. The pivots of the quadrants must point in the correct direction. For example, if the roller-path inclination of the director was positive at 0°, the fore-and-aft quadrant should be placed with the pivot pointing forward. The actual values of the inclination at these points may be read from the sine curve of the director's roller path. Remember that the inclination is read from the AXIS OF THE SINE CURVE, not from the axis of the graph.

The actual alinement is performed as follows:

1. Obtain the correct readings for the quadrants from the graph of the director's roller-path data.

2. Make sure that the quadrants are adjusted to read zero when exactly level.

3. Remove the top cover of the instrument, and attach four machined blocks (available in the naval shipyard) to the cover studs.

4. Set the quadrants to the correct readings, and place them on the blocks.

5. Loosen the three holding-down screws of the stable element and place shims under the instrument until the quadrant bubbles are centered. The quadrants must be removed while a shim is being placed or removed, and then replaced on their blocks. The three screws do not form an equilateral triangle; consequently it is difficult to compute the shimming in advance; it is easier to shim by trial and error. When the instrument case is almost in the correct position, tighten the holding-down bolts after each adjustment before checking the quadrants. This is necessary, since the case will move slightly as the bolts are tightened.

6. When the case is adjusted properly, place the stable element in operation, and train the gimbal to various bearings. The reading of the level dials should correspond to the inclination of the director's roller path at that bearing, as read from the sine-curve plot of the director's roller path.

## Correcting to the Phantom Plane

The preceding steps complete the calculations for a secondary battery; the alinement in elevation is completed when the roller-path inclination compensators have been adjusted to the settings computed for the individual elements. In the case of the main battery, however, one possible step remains. This is known as correcting to the phantom plane. While this correction is no longer made in practice, it has been included because of the principle which it illustrates.

In figure 9–21 part *A*, range *R*1, from gun No. 1 to target *T*, is less than range *R*2 from gun No. 2 to target *T*. The error introduced in range by this difference is known as horizontal displacement.

If target bearing is 0°, the range error due to horizontal

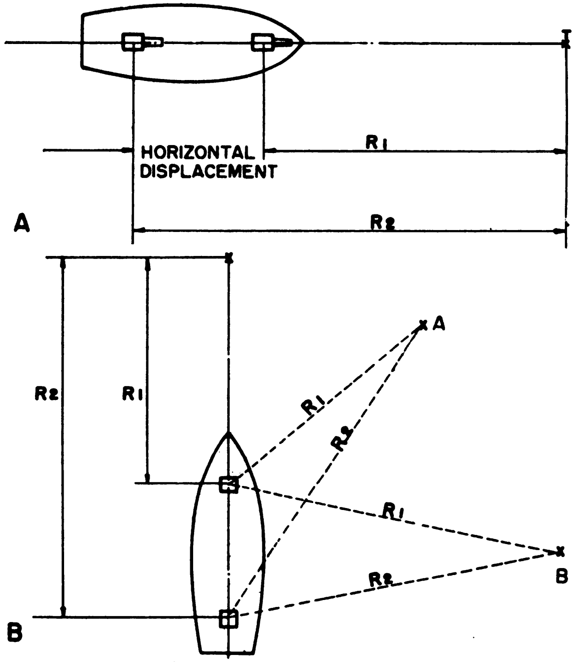


Figure 9–21.—Horizontal displacement.

displacement is a maximum. When the target is directly on the beam (target *B*, fig. 9–21 part *B*), the error is zero. As the target moves toward the stern, the error increases in the opposite direction. Thus the range error due to horizontal displacement is sinusoidal, varying as the sine of the angle of train. In this respect it is similar to the error due to roller-path inclination. This horizontal displacement error was corrected formerly by a further correction added vectorially to the existing correction on the roller-path tilt corrector. In substance, the guns were elevated from a nonexistent plane that was accordingly called a phantom plane.

Note particularly that the range error due to horizontal displacement is independent of range. However the gun elevation correction for this error is proportional to range, because the change in gun elevation required to produce a given change in range varies with range. Thus the phantom-plane correction was correct for one range only. In the past it was customary to assume a mean battle range and correct for that range, the error at other ranges being slight.

## QUIZ

1. The transit measures angles in planes that can be defined by fire-control symbols as
   a. $B'r$ and $\boldsymbol{E}$.
   b. $Br$ and $E'g$.
   c. $Br$ and $E$.
   d. $B'r$ and $\boldsymbol{E}$.
2. The actual alinement must be preceded by a check of
   a. synchro transmission system.
   b. computer and stable element.
   c. synchro transmission system and regulators.
   d. director, radars, and rangefinders.
3. After computing the center of rotation of a mount,
   a. proceed with the alinement.
   b. check it with a plumb bob.
   c. mark it permanently on top of the mount.
   d. check it with a transit and mark it permanently.
4. Peep sights are used in a telescope to reduce
   a. parallax.
   b. light reflections.
   c. collimation.
   d. convergence.
5. The final step in the alinement of the director in train is
   a. reading and establishing zero train.
   b. paralleling the lines of sight.
   c. adjusting the synchro generators to transmit zero.
   d. reading and recording the bench mark.
6. The tram readings for the mount are engraved on the
   a. tram blocks.
   b. tram bar.
   c. tram block cover plates.
   d. inside of the tram block cover plates.

7. The alinement of the battery in train is concluded with a check on
    a. accuracy of the gun and director mount dials.
    b. accuracy of the parallax system.
    c. dynamic accuracy of the receiver regulators.
    d. alinement of the receiver regulators.
8. The reference plane used in the alinement in elevation is usually
    a. an actual plane on the ship.
    b. an imaginary plane.
    c. the deck plane of the ship.
    d. a horizontal plane through the deck of the ship.
9. Present specifications require that the roller paths of the directors and guns be within
    a. 15′′ of one another.
    b. 15′ of one another.
    c. 6′ of one another.
    d. 6′′ of one another.
10. Roller-path data are taken on a stable element by means of
    a. a micrometer transit.
    b. rotating the gimbals and noting changes in the level output.
    c. a gunner's quadrant.
    d. a transit and a dial indicator.
11. The number of methods of alining the stable element to the reference plane are
    a. 1.
    b. 2.
    c. 3.
    d. 4.
12. When can direct reading be used to establish and offset centerline?
13. What is the most important phase of the elevation alinement?
14. Name the two methods of establishing the director elevation bench marks.
15. Once the reference plane has been chosen and its tilt determined, what type of diagram is used to refer the other elements of the battery to this plane?
16. Name the two methods of finding the center of rotation of a mount.

# CHAPTER 10

## SPOTTING GUNFIRE

### INTRODUCTION

Spotting is an integral part of fire control and is the act of estimating how far your own shots are missing the target. The SPOTTER is the person who does the estimating and he is, of course, a member of the fire-control party.

Unfortunately, no matter how accurately the guns and instruments may be alined, there is always the possibility of errors. Therefore, the ultimate responsibility for hitting rests with the spotter. Perfect teamwork and coordination are essential between the spotter and other members of the fire-control party; therefore, it is necessary for all fire-control personnel to understand spotting.

The material in this chapter can be considered under two broad headings: optical spotting (surface and air), using telescopes, binoculars, rangefinders, or the naked eye; and radar spotting (surface only), using any one of a number of radar systems.

### SPOTTING ANALYSIS DEFINITIONS

In noting where the shots fall during gunfire so that the necessary corrections can be made, it is mandatory that the spotter have at least an elementary knowledge of salvo analysis. The following definitions relate to terms used in connnection with such analysis:

A SALVO consists of two or more shots fired at the same target at the same time, or within a short interval of time, such as the duration of a firing signal.

THE MEAN POINT OF IMPACT (MPI) is a point about which the impacts tend to cluster or is so located that the algebraic sums of the distances of the several impacts from the MPI are each equal to zero. (See fig. 10–1.)

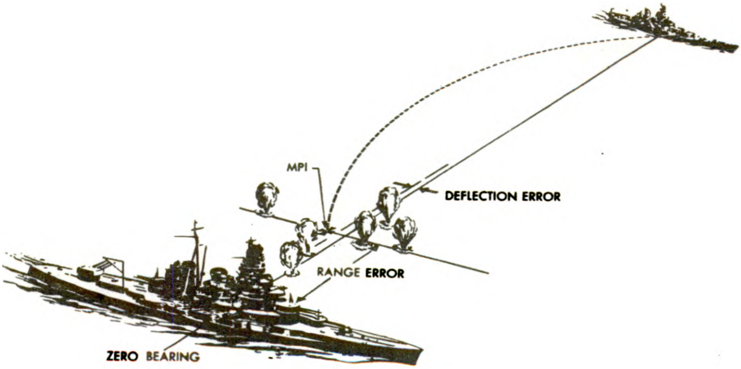


Figure 10–1.—Mean point of impact.

A **WILD SHOT** is a shot whose dispersion is abnormal in comparison with the dispersion of other shots fired in the same salvo. A shot may be wild either in range or in deflection.

The **PATTERN** of a salvo in range is the distance, measured parallel to the line of fire, between the point of impact of the shot falling farthest beyond the MPI and the point of impact of the shot falling farthest short of the MPI, excluding wild shots. The **PATTERN** in deflection of a salvo is the distance, measured at right angles to the line of fire, between the point of impact of the shot falling farthest to the right of the MPI and the point of impact of the shot falling farthest to the left of the MPI, excluding wild shots.

The **DISPERSION** of a shot is the distance of the point of impact of that shot from the mean point of impact of the salvo. Dispersion in range is measured along the line of fire and in deflection at right angles to the line of fire. Dispersion in deflection is positive when the shots fall to the right of the MPI. The algebraic sum of the dispersion in range (or deflection) of the several shots of a salvo must equal zero.

The DANGER SPACE is the distance, measured along the line of fire and in front of the target, so that, if the target were moved toward the firing point, a shot striking the base of the target in its original position would strike the top of the target in its new position. (See fig. 10–2A.)

The HITTING SPACE for a target is the distance between the base of the target to that point behind the target that a shot striking the top of the target will strike the horizontal plane. (See fig. 10–2B.)

The ERROR OF THE MPI is the error in range and deflection of the MPI of a salvo from the center of the hitting space, measured parallel to the line of fire in range and at right angles to the line of fire in deflection.

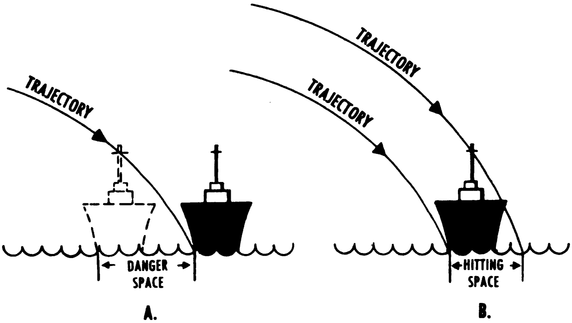


Figure 10–2.—Illustration of danger space and hitting space.

A STRADDLE in range is obtained from a salvo when, excluding wild shots, a portion of the shots of the salvo falls or bursts short of the target and the rest falls or bursts beyond the target. A straddle in deflection is obtained when shots of the salvo fall or burst both right and left of the target.

## ERRORS CAUSING DISPERSION

If a battery of guns rigidly fixed at the same angle in train and elevation were fired, variations in range and deflection would be caused by GUN ERRORS, which are:

(1) Differences in weight and temperature among individual powder charges.

(2) Differences in projectile weights.

(3) Variations in the angle of projection.

(4) Differences in projectile seating causing variations in density of loading and initial velocity.

(5) Differences in erosion among several guns with corrections not precisely made.

(6) Differences in droop among several guns, and variations in droop with temperature changes.

(7) Variations in the amounts various gun mounts yield, and irregularities in the action of the recoil mechanisms.

(8) Differences in alinement of the guns.

The above variations, no matter how slight, justify acceptance of the fact that dispersion in the points of fall of projectiles from several guns fired in salvo can be expected even under ideal conditions.

**Accidental errors.** If a battery of guns were all fired at the same instant with the same sight angle and deflection, all the projectiles would still not hit the same spot. This fact is due to accidental errors causing dispersion.

**Accidental errors due to personnel.** Some errors are introduced when the guns are positioned by pointers and trainers. The ship's motion can cause misalinement of the sights on the target when the guns are fired because one pointer may be bringing his line of sight on the target by elevating while another may be doing so by depressing, thus introducing opposite, although slight, vertical components of velocity due to the motions of the guns about their trunnions. The same effect may result from failure to fire simultaneously, in which case different guns fire at different velocities of ship's motion. Personnel errors of this type are practically eliminated by automatic positioning of the guns from a central control station.

**Effect of accidental errors on pattern size.** Accidental errors cause normal dispersion yielding a certain pattern size at a particular range. The pattern size at various ranges for the battery of a ship is observed and used as a standard for that battery in spotting the MPI of a salvo to a target. Wild shots are not considered in the determination of the pattern size because they are more likely to result from a mistake rather than from an accidental error. For example, a powder bag loaded with its ignition end forward is a mistake and will probably cause excessive dispersion. Also, if a sightsetter were to set a range of 15,000 yards instead of the correct setting of 10,500 yards, that gun would fire a wild shot which would be due to a mistake.

DESIRABLE PATTERN SIZE. If the MPI is at the desired point of impact, a pattern of small dispersion is expected to yield the maximum number of hits. However, where excessive accidental errors are allowed to creep in, excessive dispersion results. In such a case the pattern is so spread that few shots are grouped around the desired point of impact; therefore, a minimum number of hits is probable. From the standpoint of a maximum number of hits, it would seem desirable to eliminate accidental errors completely so as to have a zero pattern in range and deflection, that is, to have all the shots grouped around the MPI. Such a pattern would be desirable if the MPI were always at the desired point of impact, however it is difficult, in actual firing, to place the MPI exactly at the desired point of impact. Since it would be better to hit with some shots than to miss with all, a fairly large pattern has certain advantages. In practice, a compromise is effected. The pattern is not made as small as it might be nor is it too large for real effectiveness.

### Errors Causing Shift of MPI

ACCIDENTAL ERRORS. Since dispersion of individual shots is caused by accidental errors, it is logical to assume that no two salvos will be exactly alike and hence the MPI of the shots in a given salvo can be expected to differ in location from the MPI's of other salvos. Thus there is a dispersion of individual MPI's from the aggregate MPI of several salvos which can be determined only by analyzing firing results.

The average shift between successive MPI's is usually so small as to be difficult for the spotter to estimate. Therefore, the spotter should not be too quick to spot when only one or two salvos seem to wander off the target during a string that is, in general satisfactory.

CONTROL ERRORS. The only accidental errors so far considered have been those which the spotter must recognize as causing dispersion of individual shots in a salvo and dispersion of the MPI for several salvos. Recognition of these accidental errors helps the spotter to distinguish them from another class of errors which more decidedly affect the MPI of a salvo. This latter class of errors is known as CONTROL ERRORS or CONTROL INACCURACIES.

Before the first salvo is fired at a target, all possible effects causing error of the MPI are accounted for. If this salvo has an error of MPI, the causes for the error are the result of control inaccuracies. There are four general control inaccuracies which may cause an error of the MPI. These are listed in the order of the probable frequency of their occurrence and the magnitude of their effect:

(1) Rangekeeper set up with incorrect range, courses, and speeds.

(2) Ballistic corrections based on conditions not existing at the time of firing (initial velocity, wind, air density, powder temperature, and others).

(3) Battery not properly alined with the director. This does not mean the alinement between the guns of the battery. Such alinement results in greater dispersion and larger pattern sizes but does not materially affect the error of the MPI of the salvo. This misalinement refers to that which may exist between the controlling director and the battery as a whole. This type of error is generally caused by failure to make a director check of the battery and ALL other directors. Thus, a battery which is alined with one director is not necessarily alined with another which may be in control. Frequent director checks can assist in eliminating this type of error in the MPI.

(4) Indeterminate errors (class *B* and personnel). Class *B* errors are due to the fact that, in fire-control instruments, some of the computations are approximations in order to simplify the mechanism without seriously affecting the final

output. These class *B* errors are small in magnitude for normal ranges and therefore acceptable as causing minimum error in MPI. When class *B* errors are known to be large, such as at extreme short or long range, they are not admissable as accidental and steps must be taken to correct for them.

The other class of indeterminate errors is assignable to control personnel. For example, the director pointer or trainer may not have been on target when the salvo is fired. Small errors of this type cause only a small shift of the MPI and should not be corrected for by the spotter. The director operators should inform the spotter of large discrepancies in the point of aim in order that the spotter may differentiate this error from the others.

Summation of errors. During firing a spotter cannot sit in his aloft station and carefully analyze each fall of shot to determine the exact MPI of a salvo. Splashes last only a matter of seconds and the firing situation is probably changing even during that short interval. The spotter must have previously analyzed all probable errors, such as have just been covered, and the reasons for them. This knowledge, coupled with practical training, will enable him to make instant and intelligent decisions as to the proper correction or spot to hit the target. In summation, the general errors attending shipboard firing are:

(1) Accidental gun errors causing dispersion of shots. These errors are only compensated for to the extent of achieving desired pattern sizes. Most of the errors are eliminated by careful design, normal upkeep of the battery, and the training of the gun crew.

(2) Accidental gun errors causing a shift in the MPI of successive salvos. This shift is usually small and should be corrected when excessive.

(3) Control inaccuracies causing error of the MPI. It is the primary duty of the spotter to "spot" the corrections in range and deflection (also fuze range in AA fire) necessary to bring the MPI of a salvo to the desired point of impact. He should recognize the first two classes of errors

in order to correctly spot the error of MPI caused by control inaccuracies.

# THE SPOTTER AND METHODS OF SPOTTING

## QUALIFICATIONS

The following are the qualifications for spotters:

(1) Imperturbability.—Even, calm temperament, not excitable under stress.

(2) Sound judgment.—Ability to evaluate situations, causes and appropriate action to be taken.

(3) Decisiveness.—Ability to make up his mind.

(4) Coordination.—The spotter is called upon to make many practically instantaneous decisions. He must coordinate what he sees, hears and thinks.

(5) Alertness.—Be aware of all that is going on about him.

(6) Keen eyesight.

(7) Normal hearing.

(8) Distinct speech and clear enunciation.

## GENERAL FUNCTIONS AND DUTIES OF SPOTTERS

The primary function of the spotter is to correct the actual range and deflection errors to establish the hitting gun range deflection. Failure to correct initial errors promptly and accurately may conceivably be the deciding factor in a naval engagement, which fact makes apparent the importance of the spotter in relation to the accurate control of gunfire.

There are other functions regarding fire control which the spotter must perform before and during fire. In general these are:

(1) Describe the enemy forces (general bearing line, number of ships and deployment).

(2) Estimate all values necessary for initial positioning and tracking of the prescribed target ($R$, $Br$, $E$, $A$, $dH$, and $Sh$ for air targets; $R$, $Br$, $A$, and $S$ for surface targets during firing).

(3) In addition to spotting the fall of shot, report changes in target angle and speed. If necessary, report changes in range.

(4) Keep control informed of the tactical situation, if required to do so.

The spotter is required to perform other duties in connection with the control of gunfire. The exact nature of these duties varies in different type ships, depending on the particular fire-control organization in effect. The spotter's detailed duties and spotting procedures are prescribed in the ship's battle bill and in fleet doctrinal publications. It is assumed that, as an FT2 or FT1, you are familiar with the methods of estimating target course and speed, since they have been discussed in previous courses. This text is limited to the spotter's other most important function, the observation and correction of the error of the MPI or air burst by standard methods of spotting.

## SPOTTING ERROR OF MPI IN DEFLECTION (SURFACE)

Correcting the deflection is extremely important, not only because salvos must be on to hit, but also because in long range surface fire it is very difficult to spot on in range if the deflection is excessive. If other means of spotting in range are not available, such as aircraft observation or shipboard measuring devices, a salvo which is widely off a single target should first be spotted in deflection and the succeeding salvo spotted in range. With a number of targets in formation it should be possible at once to spot in both range and deflection. In estimating deflection spots, the estimated target width in mils should be used as a guide. Also telescopes, binoculars and stereo rangefinders fitted with mil scales furnish suitable means of estimating deflection errors.

With a high speed target, the spotter should bear in mind that the apparent MPI in deflection should be held abaft the point of aim in order to allow for the travel of the target while the splashes are forming. It must not be assumed that full splashes form instantaneously at the impact of the salvo. The time lag is only a few seconds at most, varying with the caliber of the projectile, but it is sufficient to allow considerable movement of a high speed target.

## SPOTTING ERROR OF MPI IN RANGE (SURFACE)

With good visibility and a spotting height of 100 feet or more, the error of the MPI can usually be estimated with reasonable accuracy at ranges up to about 15,000 yards. This is accomplished by observing the position of the bases or slicks of the splashes relative to that of the waterline of the target.

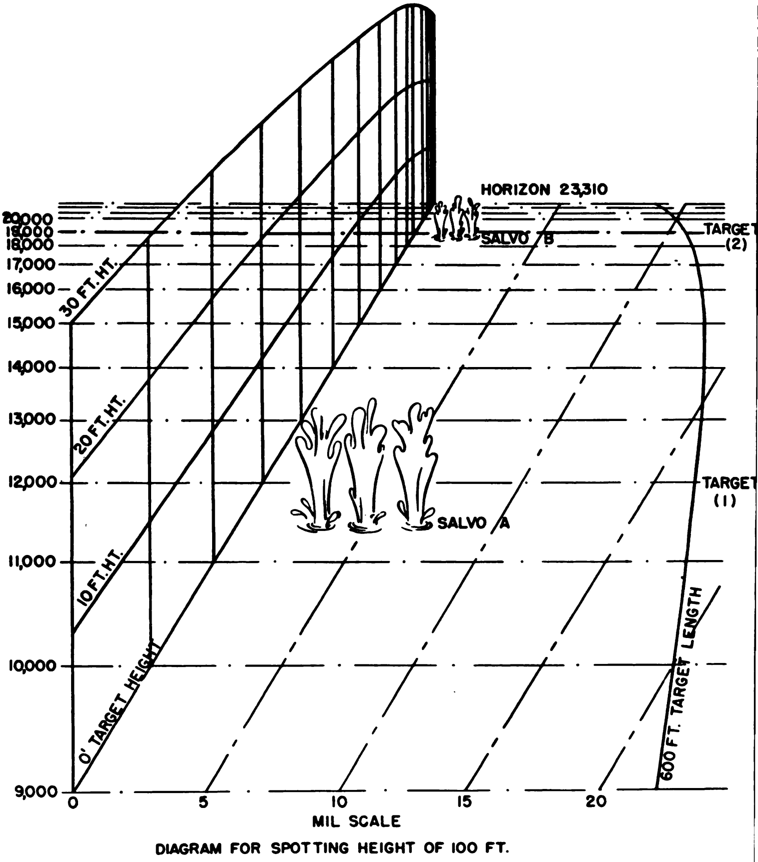


**Figure 10–3.—A typical spotting diagram.**

Experience in determining this range error can be gained by actual firing at target practice and by practicing on a spotting board which simulates the actual conditions of splashes relative to the target as viewed from the spotter's station. Spotting diagrams are used in conjunction with such training to indicate the relative displacement of a salvo from the target. Figure 10–3 shows a typical example of a diagram for a spotting height of 100 feet and target heights of 10, 20, and 30 feet. Such a diagram is constructed by means of dip curves for the particular height of the spotting station. Range lines are drawn at intervals of 500 or 1,000 yards from a minimum range to that of the horizon. The distances between these range lines represent the apparent range differences as viewed by an observer at the height in question. The method of construction of dip curves are available in Fleet training publications aboard ship and will not be described here.

Study of the figure 10–3 makes it evident that salvo *A* is short of the imaginary extension of the waterline of a target at 12,000 yards by about 500 yards. However, the error of a salvo fired at a target at 20,000 yards is not as apparent. The 500 yards error of such a salvo (indicated on the diagram as salvo *B*), appears as little or no error in apparent distance from the extended waterline of the target. Thus it can be seen that, for shipboard spotting at such a range, the splashes must be in line with some portion of the target before the spotter can reasonably tell whether the salvo is over or short, to say nothing of estimating the amount of the MPI error.

## METHODS OF SPOTTING

Subject to the procedures which are laid down in Fleet and Force doctrines, there are five methods of visual spotting, the use of any one of which is determined by the type of battery firing, type of target, visibility, and range. The methods are as follows: (1) direct method, (2) bracket or halving method, (3) ladder method, (4) barrage method, and (5) tracer method.

Direct spotting is a method of spotting in which the splashes or bursts are spotted direct to the target. The spotter estimates the error of the splash or burst and makes a spot which will, in his estimation, cause the next shot to hit the target. This is the most desirable procedure, but its use is limited for surface fire. For AA fire, in conjunction with the stereo rangefinder, it is the only practicable visual method used by the Navy. For surface fire this method requires a height of 120 feet for ranges up to 15,000 yards. It is also necessary that the splashes be relatively close to the target, and that the rangekeeper set-up be fairly accurate. These considerations limit the direct method, for the larger caliber guns, to relatively short ranges.

THE BRACKET OR HALVING METHOD is used at long ranges for the main battery when no air spot is available. It has as its basis the fact that at great distances it will be impossible to tell if a splash is short or over a target unless the two are in line. If the target and splash are not in line, or if the splash does not line up with a ship in the formation whose range is approximately that of the target, the first spot is made in deflection only. When target and splashes are in line in deflection, a range spot is made in such a direction and amount as to cross the target definitely. The direction of the next spot is reversed and the size of the spot is cut in half. This halving is continued until a straddle is obtained. The spot should not be reduced below pattern size. Once a straddle is obtained, only centering deflection spots should be made as long as the spotter is sure he has both short and over splashes. If, however, over splashes are obscured by the target or by shorts, every third or fourth salvo should be fired with an up spot of one pattern size so as to lift the entire salvo over the target. Only by this procedure can the spotter be sure his straddles were not all shorts in reality.

Normally, when using this method, slow fire is employed until at least one straddle is made. In slow fire, the firing of a salvo is held up until the previous salvo has landed, the spot has been made, and the corrections applied for the succeeding salvo. When a straddle occurs, rapid fire is usually ordered by the controlling officer. In rapid salvo fire, fire is maintained without waiting for each salvo to land and for spots to be made and applied to each succeeding salvo. In such a case a spot is made whenever possible and applied to the gun range of the salvo to which the spot was applicable.

THE LADDER METHOD is of greatest value when optical ranging is difficult and visibility poor due to fog, smoke, or darkness. It is particularly adaptable to fast moving targets. There are many variations of this method. However, it is necessary only to understand its fundamental principles. Fire is deliberately opened short and succeeding salvos are fired so as to approach the target in steps not less than pattern size. As soon as the target is crossed, the steps are reversed and halved until the target has again been crossed. After a salvo has straddled the target, circumstances such as rapidly changing target course and speed may make it desirable to continue with a "rocking ladder," which moves the salvos back and forth across the target. Under other conditions it is better to cease spotting as long as hits are obtained or the straddles appear to be straddling the target. In using the "rocking ladder" mentioned above, it is well to remember that, if a spot is required, it must be made only on a salvo fired at the "zero spot" range in order to prevent confusion and "spot pyramiding."

THE BARRAGE METHOD is more a feature of control than a type of spotting. It consists of placing a zone of fire short or over the target, according to whether the target is closing or opening the range. The gun range is kept constant until the target passes through the zone of fire and then is raised or lowered as necessary to force a second passage of the target through the barrage. This procedure is followed until the target is destroyed or has moved out of range. This system is usually used by small caliber fast firing batteries against light fast-moving targets. It is the spotter's function to determine when the barrage should be shifted, in which direction and how much.

THE TRACER METHOD of control consists of spotting shots by noting the error as the tracer passes the target. It is used chiefly in spotting machine gun fire. Against fast moving air targets, the tracer stream appears to curve towards the stern of the target due to the bearing rate of the target. Hits will be obtained when the tracer stream appears to pour into the bow of the target. This method, in addition to the others, may also be used with the larger caliber projectiles, particularly at short ranges. At longer ranges tracers are of doubtful assistance to the spotter because of the difficulty of keeping them in sight or in judging when they pass the target. Under certain conditions of light, the tracers cannot be seen clearly and should not be relied upon except at short ranges.

Short range spotting differs from other spotting problems in that range errors are not so difficult to judge. However, in determining deflection errors at short ranges, consideration must be given to the travel of the target and to the spotter's position relative to the line of flight of the projectile. For example, with the firing ship and target on opposite courses, target to starboard, a shot fired with the correct deflection but long in range will appear to the spotter to have a deflection error to the left of the target. Special short range diagrams are constructed as an aid to the spotter in this type of firing; instructions for their use and construction are available in publications carried by all ships.

## SPOT PYRAMIDING

Spot pyramiding is the application of a new spot before the effect of a previous spot has had time to become apparent. It can occur only at rapid fire, when the interval between shots or salvos is less than the time of flight plus spotting interval. In that case, at the time a salvo lands there are one or more other salvos in the air at the same time. Suppose the spotter makes a spot on the salvo which has just landed. This spot is applied and a new salvo is fired with the corrected ballistic thus arrived at. Then one or more of the salvos which were already in the air lands, and the spotter, forgetting that his previous spot has not had time to show its effect on the fall of shot, spots again. This spot is applied to the next salvo fired, which means that this latter salvo is over corrected and will probably miss, as will subsequent salvos until the spotter sees his mistake and spots back again to remove the pyramided spot.

In order to help the spotter avoid pyramiding, the time of flight signal mechanism is used. This mechanism may be incorporated in the rangekeeper or in the form of a separate time of flight clock. It is operated by the rangekeeper operator or an assistant, who presses a button when the salvo on which a spot is applied is fired. Just before the salvo lands, the mechanism sounds a buzzer which informs the spotter that a spotted salvo is about to land. When this system is used, after making a spot the spotter waits for the buzzer before making another spot.

Spot pyramiding is a very common fault and has a disastrous effect on fire control. Every means available must be used to prevent it, and these means must be carefully and correctly operated. If they are improperly operated, they may cause worse errors than they are designed to prevent. For example, if the time of flight mechanism operator forgets to press the button for a spotted salvo, and the spotter waits for it, he may continue to wait after it becomes apparent that his previous spot was incorrect. In such a case, the operator making the mistake should advise the spotter of the situation as soon as he himself realizes it.

## THE OFFSET WEDGE ATTACHMENT FOR SPOTTING OFFSET BATTLE PRACTICES

The offset wedge attachment is designed to fit the 7×50 binoculars used by the spotter and is intended for use during OFFSET battle practices. The attachment consists of a perforated plastic achromatic wedge prism held in a removable mount in front of each objective lens of the binoculars. In normal circumstances the standard offset used (between the target ship and the point in its wake where the projectiles should land) is four degrees or 70 mils. Therefore, the wedge prism is constructed so that part of the light passing through it is deviated four degrees (+1 minute), while the rest of the light (that which passes through the perforations in the wedge prisms) is undeviated. The effect this has is to produce two images of every object, one deviated and one undeviated, both visible at the same time but with a four-degree separation. When two observed objects such as the target ship and the projectile splashes of a salvo are exactly four degrees apart, the deviated image of one will be superimposed upon the undeviated image of the other. The offset battle practice spotter using binoculars equipped with an offset wedge attachment makes his spots in the usual manner, his objective being to superimpose the fall of shot on the target ship.

## ANTI-AIRCRAFT SPOTTING

The direct method of spotting is used almost exclusively for anti-aircraft spotting with projectiles using a fuze setting. With this method the rangefinder operator is also the spotter. He views the burst and the target stereoscopically through the rangefinder and uses his depth perception to estimate the errors. Sometimes two spotters are employed, one to spot in deflection and elevation while the stereo operator spots in range only. When only one spotter is used, he must be able to distinguish whether it is range, deflection, or elevation causing the error; and, because of the rapid development of the air problem, this can be very difficult. With another spotter or the control officer doing the spotting in deflection and elevation, the rangefinder operator is relieved of that duty and can devote all his faculties to determining the range error.

**Spotting deflection and elevation.** When an additional spotter is used, he must take apparent offset into account. Apparent offset in deflection is proportional to the bearing rate. In a horizontal bombing attack on own ship, this would be so small as to be almost negligible, and the spotter can spot deflection direct to the target; but in a bombing attack on another ship, where the bearing rate is large, the apparent offset might be large when the range error was large. Shorts should lead the target and overs should lag provided the computer set up is correct in all elements except range. The deflection spotter should know this approximate range error in order to visualize correctly the proper apparent offset. For this reason he must coordinate his spots with the range spotter. By listening to the range spotter's spots he knows the approximate range error, and can thus determine whether the apparent deflection errors are true errors or are due to apparent offset.

Similarly in elevation, when the elevation rate is small the apparent offset is negligible and the spotter can spot direct to the target. This is the case in a low position angle target. But as the target approaches and passes overhead, the position angle increases and the elevation rate increases. When the elevation rate is high the apparent offset will be large if there is much range error. Here again shorts should appear to lead the target and overs to lag, provided the computer setup is correct except for range.

SPOTTING RANGE. The stereo spotter is not concerned with the foregoing paragraph unless he is doing all the spotting, i. e., range, deflection, and elevation. If he is spotting range only, he ignores the deflection and elevation errors and keeps the other spotter informed of his range spots. It is best for the range spotter to rely on his stereo depth perception for all spots. Some spotters use the tracer, but since the tracers create an optical illusion, watching the tracer to spot in AA fire is very deceiving. Except at close-in targets, the tracers appear to pass under the target and rise beyond it, which may confuse the spotter. In all AA fire the spotter must be absolutely certain of the direction of error before he applies a spot. If he spots an over as a short, the target aircraft can be in, accomplish its mission, and be gone long before the error can be detected and rectified. If the bursts appear to be at the same range as the target, caution should be exercised in making a spot. But if they are definitely all over, by all means a spot should be applied. It is important to consider the fact that a burst short of the target aircraft may injure personnel, while a burst beyond is lost.

At the instant of burst a flash of light appears which is immediately obscured by the smoke of the burst. This flash is the ideal point to use for spotting, if possible, since it shows the true position of the burst relative to the target. When an air target is hit, the flash and smoke of the burst will be seen, and, in addition, the plane will wobble or jump and sections of it may disappear.

## EFFECTIVE VOLUME OF BURST

The projectiles used for AA fire are known as high explosive. They are not shrapnel. When they detonate properly, that is, in a HIGH-ORDER BURST, they make a dark brown or black smoke. Sometimes they fail to detonate properly (in a LOW-ORDER BURST), and then the smoke is yellow or white. With a high-order burst the shell is broken up into fragments which fly off at high velocity.

The shape of the volume which is swept through effectively by the fragments is roughly that of a mushroom, with the stem pointing in the direction along the trajectory toward which the shell is moving. About twenty percent of the fragments are projected along the stem, the others nearly perpendicular to that direction. The effective volume around a burst can be taken as a hemisphere of about seventy feet in radius. From this it can be seen that, to hit, the shell must burst either just short of the target or close alongside it. The mushroom shape described above must not be confused with the shape of the smoke burst which is roughly globular.

## A NOTE ON PROXIMITY FUZES

There is no method of spotting proximity (*Vt*) fuzed projectiles when they are fired exclusively, since there are no bursts unless the projectiles are within lethal range of the target. It is often desirable to be able to spot AA fire when *Vt* fuzes are being employed, however, and this is possible if a percentage of mechanical time fuzed projectiles are mixed in at intervals with the *Vt* fuzed projectiles. The resulting bursts of the mechanical time fuzed projectiles can then be used as a guide for spotting by the methods already described. Obviously this procedure is limited to the type guns (such as the 5″/38 caliber) which are equipped to set mechanical fuzes immediately before firing the projectile.

## SPOTTING WITH RADAR

Radar spotting has proven to be both accurate and reliable to the full range of surface batteries. Radar provides a means of spotting which is independent of conditions of visibility, so that blind spotting is possible with blind firing.

Shell splashes appear on the scope as fluctuating echoes which last for several seconds, depending upon the size of the projectile and the range. The large column of water thrown up by the projectile produces the echo. Salvos produce larger or multiple echoes on the scope.

If the projectile stays within the vertical limits of the radar beam, its flight to the point of impact can be followed on the scope on main sweep. The echo from the projectile produces a small, weak, moving echo which appears at the edge of the scope and moves out in range toward the target. At the point of impact, the echo stops and grows larger as the splash builds up. Echoes from direct hits will be lost in the target echo, while salvos which straddle the target may envelop the target in a mist of splash echoes on the scope thereby making it impossible to spot individual splashes.

## SCOPE PRESENTATIONS

It is possible that, with an experienced operator, almost any type of radar can be used for spotting. However, we are only concerned with the radars used in gunnery and, of these, two types of scope presentation will be discussed. They are the A-scope and B-scope.

A-SCOPE PRESENTATION. In this type of presentation the range notch is used as a measuring stick for estimating the range error. As an example, look at the illustration of the Mk 12 radar range indicator scope, with a target in gate, in figure 10–4. The range notch is 400 yards wide, while the expanded sweep is a total of 1,200 yards.

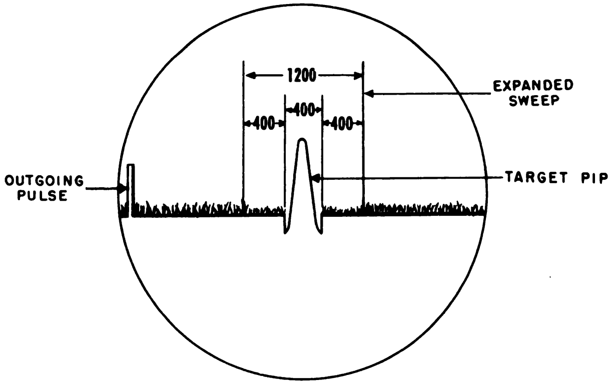


Figure 10–4.—A-scope Mk 12 radar, illustrating expanded sweep.

The 400-yard notch and the 1,200-yard expanded portion of the range sweep provide accurate reference range intervals for the estimation of range spots. During firing with the range pip at the center of the notch, the expanded portion covers 600 yards on either side of the target. With proper adjustment, the expanded portion also consists of three equal range intervals of 400 yards each as shown in figure 10–4. If the splash or MPI is estimated to fall at the

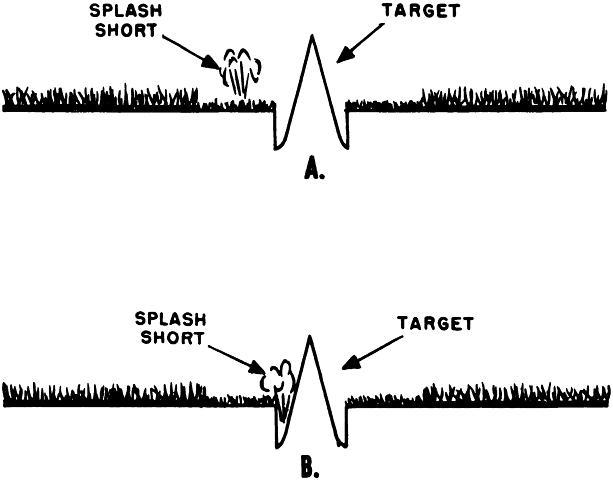


Figure 10–5.—Surface spotting, appearance of range scope.

center of the first 400 yard interval, as in figure 10–5A, the fall of shot is 400 yards short of the target. As a second example, if the splash is about half in and half out of the range notch as shown in figure 10–5B, the fall of shot is 200 yards short of the target in range. Overs are spotted in the same manner except that overs sometimes may be obscured by the target pip. As long as the splash pips are disappearing in the target pip, however, no spot should be necessary.

There is no effective way of estimating the error in deflection on the A-scope, although the trainer on the director equipped with Mk 12 may be able to see the direction of error on his scope by noting the unbalance in his matched pips or target spot movement when the projectile or salvo lands. It is not advisable to use the pip matching method on the trainers scope because accuracy of train may be sacrificed. It is advisable to spot on in range first so that most of the splashes are in the 400-yard range notch. Then, as a second step in spotting, spot on in deflection, using the trainer's target spot or meter indications.

## AIR TARGETS

When an AA shell bursts, its fragments cover a considerable volume in space and may reflect enough energy to produce an echo on the screen of the A-scope. In ranging on these echoes, operators should follow the projectile pip by eye and look for the sudden appearance of a small pulsating echo. Too much faith should not be placed in AA spotting with radar since experiments indicate that the echo comes from the shell fragments which continue to move out in range. The time for the burst to build up large enough to produce the pip is not known. If this time is appreciable, a large error will result because of the high speed of air targets. These factors must be taken into account before reliance is placed on AA spotting. As in surface spotting, the detection of deflection errors is sometimes possible, but determining the size of these errors is not possible by radar.

## VARIATIONS IN RANGE A-SCOPES

The important difference between the A-scope used in Mk 12 and those used in radars on the Mk 57 and Mk 63 Gun Fire-Control Systems (such as the Mk 28 Mod 2, Mk 29 Mod 2 and the Mk 34 Mods 3 and 4) is that, instead of an expanded sweep section on the main sweep, the whole trace is expanded when the equipment is switched to precision sweep. Therefore the only guide available in estimating the spot is the target pip width, unless the splash persists long enough for the operator to gate it, thus obtaining an accurate range.

Accurate spotting is possible only on precision sweep. This fact will make it impossible to follow the projectile flight to the target from the gun. It is likely that the operator will be able to see the projectile as it nears the target, as shown in figure 10–6 which represents the Mk 29 Mod 2 Range Scope. This figure also illustrates the problem and the appearance of the splash on the scope. Assuming the pip width to be 100 yards, the error in range of the splash, in this case, would be 100 yards.

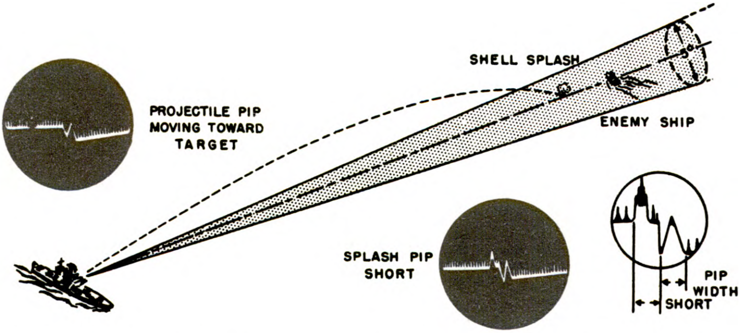


Figure 10–6.—Projectile and splash pips, radar Mk 29 Mod 2.

Figure 10–7 illustrates the same problem on the Radar Mk 34 Mods 3 and 4. In this radar, when the target is gated correctly the grass on the trace disappears and a sharp trace is seen on the scope. Again it is necessary to use the target pip width to estimate the error shown by the splash. Con-

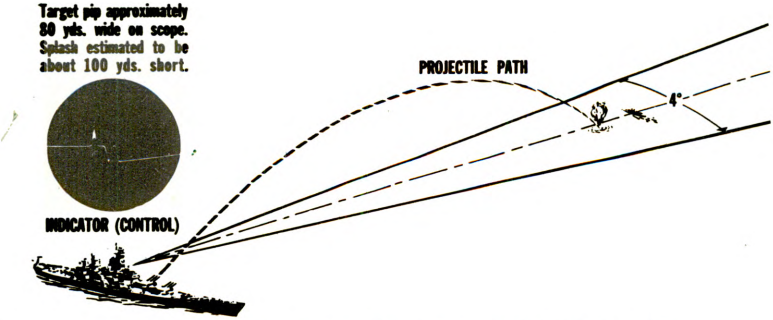

Target pip approximately 80 yds. wide on scope. Splash estimated to be about 100 yds. short.
PROJECTILE PATH
4°
INDICATOR (CONTROL)

Figure 10–7.—Spotting the fall of shot with the Mk 34 radar.

sidering the target pip width to be 80 yards, range error can be estimated to be about 100 yards in figure 10–7.

## SPOTTING SURFACE FIRE WITH B-SCOPE PRESENTATION

The B-scopes, on which the following information is based, are found in the main-battery radars Mk 13 Mod 0 and Mk 8 Mod 3.

In using the B-scope for spotting, precision sweep gives the best indications of shell splashes and is used for all accurate spotting. When firing at a long range, or when a

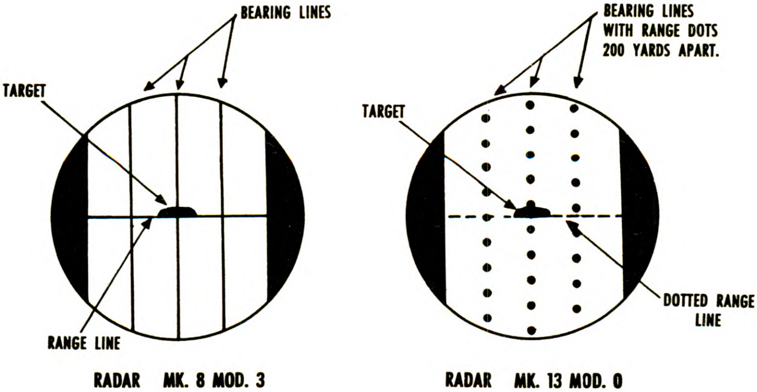


Figure 10–8.—Ranging on target with the B-scope. Target centered in bearing.

weak echo is expected, the receiver gain should be increased to make sure the shell splashes are picked up. For best results, accurate tracking with the target echo kept adjacent to the range line and bisected by the zero bearing line (as in fig. 10–8) is essential. As is obvious in figure 10–8, the scope presentation difference between the Radar Mk 8 and Radar Mk 13 is small, being only in the range and bearing lines. In the Mk 8 the range and bearing lines are solid. Therefore, in estimating a spot, it is necessary to use the target echo width as a measuring stick. This target echo width is normally about 100 yards, but it should be measured on individual Mk 8 equipment by moving the target echo down so that the top of the echo just touches the top of the range line, then noting the difference in range between this position and the "on target" position.

On the Mk 13 scope, range errors can be estimated by using the 200-yard bearing line dots as a guide. Bearing errors can be estimated with both Mk 13 and Mk 8 by using the fractional parts of the splash pips on either side of the center bearing line. Attempts to range or train on the splash echoes will interfere with smooth transmission of target range and bearing.

The following information will apply equally well to either the radar Mk 8 Mod 3 or the Mk 13 Mod 9, although the illustrations are of the radar Mk 13 Mod 0 B-scope. Keep in mind also that, even though the direct method of spotting is most often employed when using radar to spot, it may be advantageous to use some form of ladder or bracketing method. This may be particularly true on targets at longer ranges or at any other time when the splash pips do not build up sufficiently to permit an accurate estimate of the range error.

## RANGE SPOTTING

Figure 10–9 shows the appearance of single shell splashes on the radar screen. The distance from the lower edge of the splash echo to the top edge of the range line is the range spot. Since the dotted range line may be quite thick, rep-

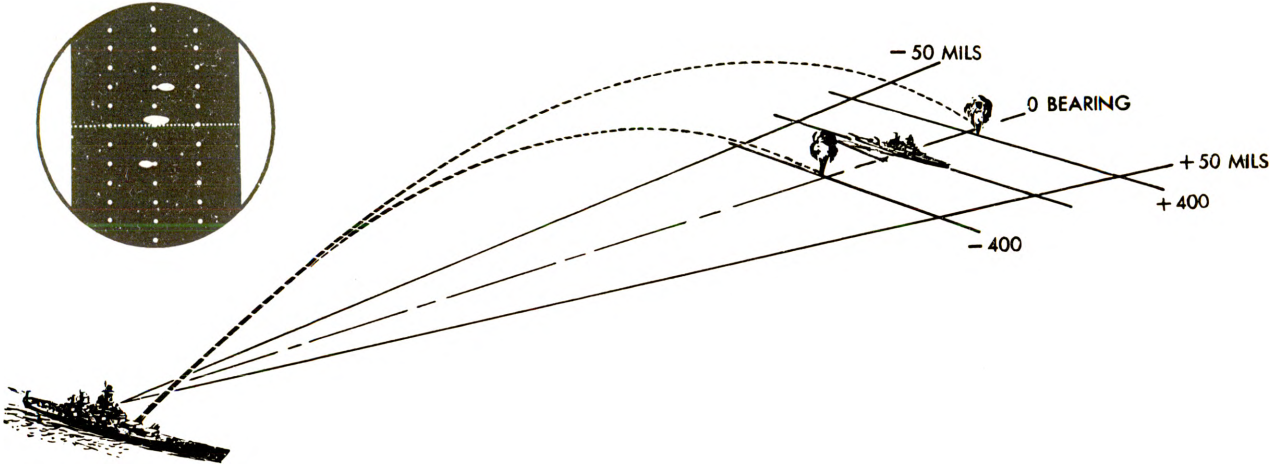
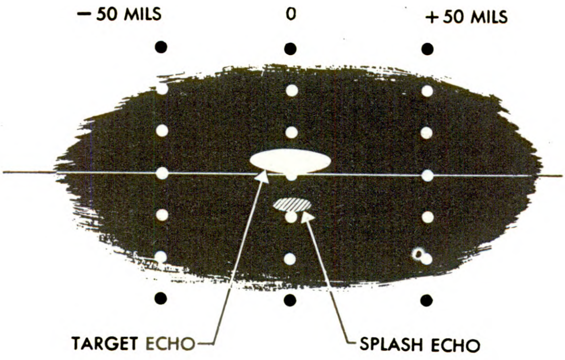
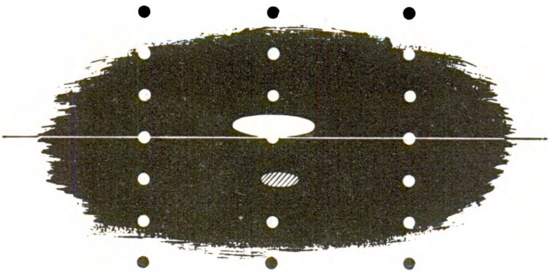


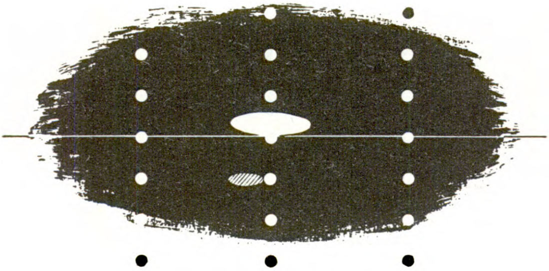
Figure 10–9.—Single shell splashes (400 over and 400 short).



A. ZERO DEFLECTION ERROR



B. ERROR — 3 MILS RIGHT



C. ERROR — 9 MILS LEFT

Figure 10–10.—Deflection spotting.

resenting as much as 50 yards in range, care must be taken that this factor is included when estimating shorts. For spotting, the range line should be adjusted by the technician so that it will be as thin as possible and still be easy to observe. This will reduce the chances of the splash echoes being obscured by the range line.

## DEFLECTION SPOTTING

Deflection patterns are usually small. To spot in deflection the measuring stick is the beam width of one degree, or 17.5 mils. Even the smallest echoes show a pip of at least one beam width so that the splash echo can be taken as approximately 18 mils.

Deflection spotting is based on the relative proportions of the splash echoes on either side of the center bearing line. For no deflection correction, the splash echo is bisected—about 9 mils of the echo on each side of the center bearing line (fig. 10–10A). For a deflection of three mils to the right (fig. 10–10B), the splash echo is divided so that about twelve mils of the echo is on the right and 6 mils on the left of the center bearing line—a ratio of approximately two to one. Figure 10–10C shows the echo at 9 mils left. Further calculation indicates that division of the splash echo in the ratio of about four parts on one side and five on the other side of the center bearing line means a deflection error on one mil. With experience and care in deflection spotting, the operator can detect a difference of this magnitude.

## SPOTTING SALVOS

When salvos are fired, several echoes (single or merged) usually are visible on the scope at the same time. With large salvos, shells will probably fall so close together that some individual splashes cannot be distinguished. This may make the spotting of salvos difficult; however, the MPI of salvos can be spotted in a manner similar to spotting single splashes. On the B-scope, the range spot is the average distance of all splash echoes from the top of the range line.

Occasionally large errors in spotting result from lack of

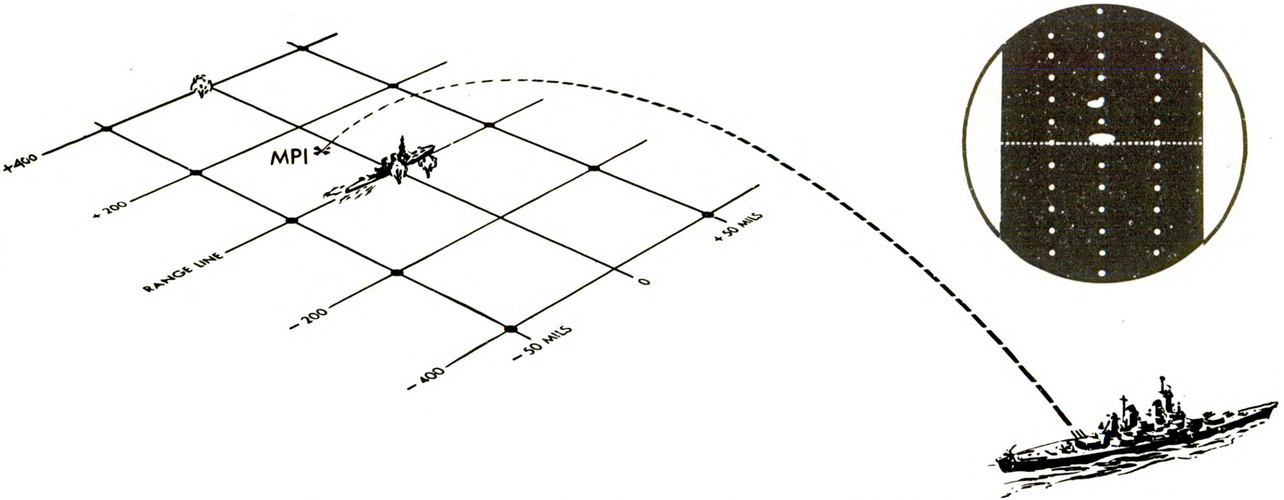


Figure 10–11.—Three gun salvo with two splashes obscured by the target.

discrimination between the echo from the splashes and the echo from the target, or from obscuring of the splashes by the range line. The dotted range line will help to minimize this latter difficulty. The radar spotter should know the number of shots in each salvo and the average range pattern size so that he can more correctly evaluate the picture he sees on the screen when the splashes appear. For example, if two splashes from a three gun salvo are within 50 yards of the target, they may not even be detected and the spotter may base his estimate of the MPI on the third splash alone (fig. 10–11). However, if he knows that there should be three splashes and what the normal pattern size of such a salvo would be, he can assume that two of the splashes were very close, which will result in a smaller and more nearly correct spot of the MPI.

Salvos may be spotted in deflection the same way as single shell splashes. The error of the MPI in deflection is estimated from the appearance of the splashes on the B-scope. Deflection errors are measured in mils to the right or left of the center bearing line of the B-scope. In spotting in deflection, splash echoes may be obscured by the target echo or the range line, as in range spotting. Likewise, several splash echoes may merge and make it difficult to estimate the error of the MPI. Figures 10–11, 10–12, and 10–13, show the MPI of salvos and the deflection errors.

The operator can spot in both range and deflection on the same salvo. Several examples of fall of shot and scope appearances will illustrate the problems involved.

A nine-gun salvo (fig. 10–12) shows the obscuring of the splash echoes with each other, with the target and with the range line. In this instance the range error of the MPI is 152 yards made up of individual errors in the fall of shot of +396, +371, +42, +133, +177, +54, −29, +25, and −3. The correct range spot is down 100. Several of the splashes merge into one echo on the scope. None of the splashes near the target appear distinctly on the scope. As a result, the splash echoes appearing on the scope render it impossible to make an accurate radar spot unless the pattern is evaluated

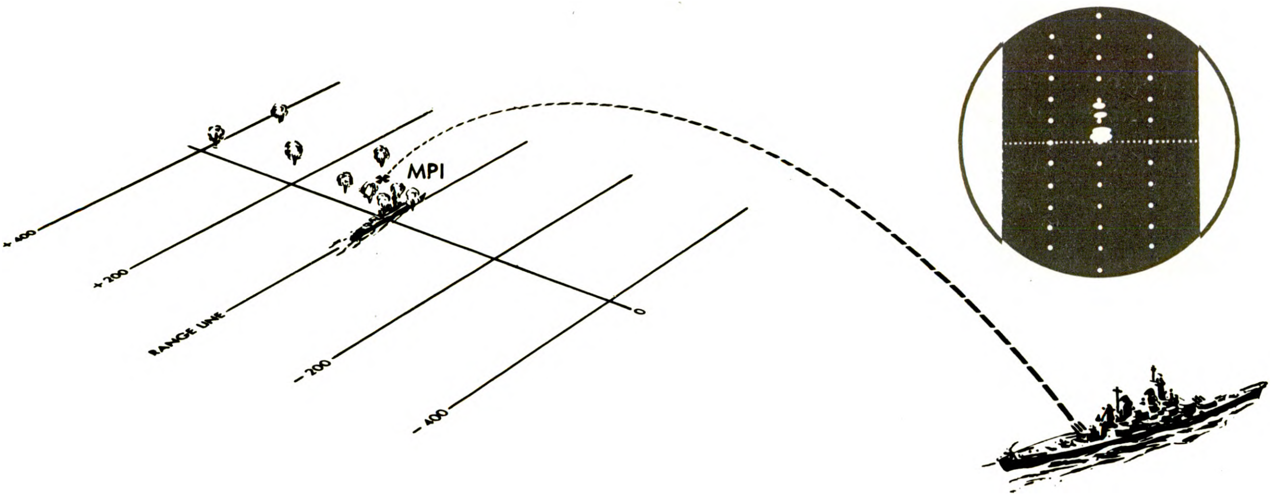


Figure 10–12.—Nine-gun salvo: MPI—152 yards.

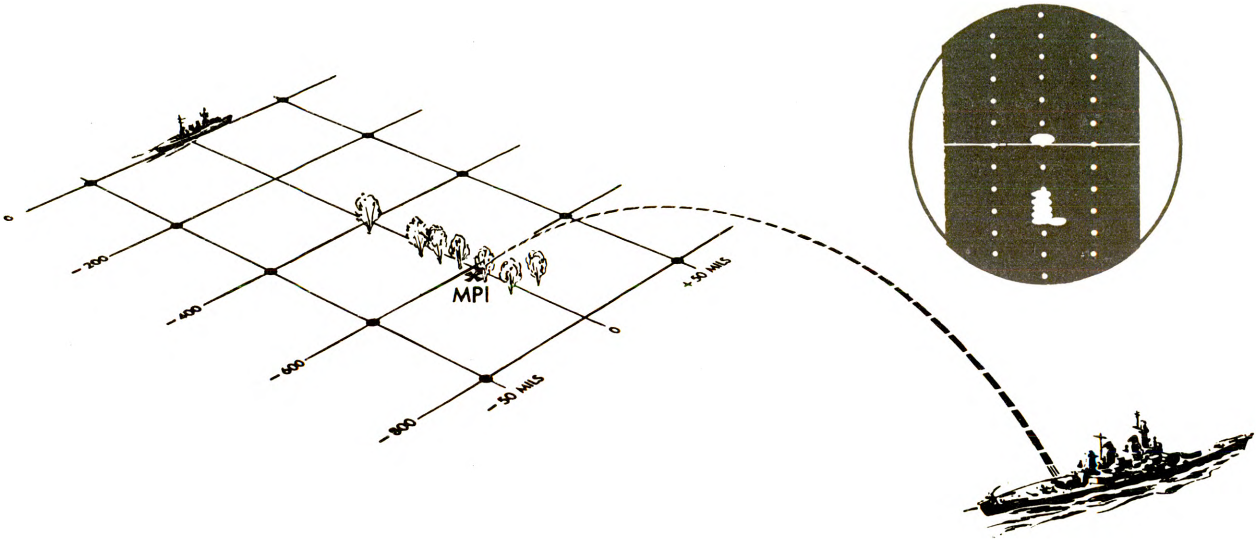


Figure 10–13.—Nine-gun salvo: MPI —603 yards, left 1.67 mils.

correctly. Splashes closer than 100 yards in range and 18 mils in deflection partially merge with the target pip.

Another nine gun salvo is shown in figure 10–13. The fall of shot error in range and deflection are:

| *Range in yards* | *Deflection in mils* |
|---|---|
| —405 | *L* 1.5 |
| —540 | *L* 2.0 |
| —570 | *L* 1.8 |
| —600 | *L* 2.0 |
| —630 | *L* 2.5 |
| —650 | *L* 3.0 |
| —655 | *L* 2.5 |
| —665 | *L* 2.18 |
| —710 | *R* 0.5 |

The error in MPI in range is —603 yards and in deflection left 2.0 mils. A good radar spot is up 600 and right two mils.

## QUIZ

1. The distance of the point of impact of a projectile from the MPI of the salvo in which it is fired is called
   a. danger space.
   [✓ b. dispersion.]
   c. wild shot.
   d. error of MPI.
2. A wild shot is a shot whose dispersion is abnormal in comparison with the dispersion of other shots fired in the same
   a. battery.
   b. salvo.
   c. firing run.
   d. day.
3. The most desirable pattern size is
   a. none at all.
   b. a very small pattern.
   c. a large pattern.
   d. one not as small as it could be, but not too large for accurate shooting.

4. Which of the following is not a method of visual spotting?
    a. Bracket.
    b. Ladder.
    c. Step-by-step.
    d. Barrage.
5. Using the tracer method of spotting on machine gun fire, hits will most likely be obtained when the tracer stream appears to
    a. enter the bow of the target.
    b. pass under the belly of the target.
    c. pass over the nose of the target.
    d. pass under the nose of the target.
6. The offset wedge attachment is used during
    a. short range battle practice.
    b. offset battle practice only.
    c. short range and offset.
    d. long range and offset battle practice.
7. When a projectile fails to detonate properly, it makes a white or light yellow puff of smoke; this is called a
    a. low-order burst.
    b. high-order burst.
    c. high-order detonation.
    d. high velocity fragmentation.
8. One of the most important reasons for using a time of flight signal is to
    a. keep from having more than one salvo in the air at a time.
    b. let the spotter know when a spotted salvo is about to land.
    c. make it possible for the spotter to pyramid the salvos.
    d. make it impossible for the spotter to pyramid the salvos.
9. Proximity fuzed projectiles can be spotted only
    a. by the bracket method.
    b. by the ladder method.
    c. when mixed with mechanical time fuzed projectiles.
    d. by the barrage method.
10. Splash echoes on the radar screen from a direct hit will
    a. show up just ahead of the target echo.
    b. show up on both sides of the target echo.
    c. show up in the target echo.
    d. be lost in the target echo.

# CHAPTER 11

## NAVAL GUNFIRE SUPPORT

### INTRODUCTION

In the course of World War II, naval task forces frequently carried out bombardments of enemy installations on shore. Shore bombardment techniques improved materially during the war, and the most important development was the use of naval gunfire to support the landings of troops on defended enemy territory.

The mission of naval gunfire in aid of landing operations is to support the seizure of the objective by reducing or neutralizing shore installations and enemy troops that oppose our forces both prior to and during the landing, and by assisting the advance of our troops after the landing has been made. The support provided is particularly necessary during the time after the troops have landed but before adequate artillery can be brought into action. To be successful, naval gunfire support for troop-landing operations must be carefully planned in advance, and must be executed with skill and dispatch. Full exploitation of this support can be achieved only if ground, naval, and air personnel understand the organization, basic techniques, capabilities, and limitations of naval gunfire support, and follow the standard procedure which has been agreed upon by the joint services.

### ADVANTAGES OF NAVAL GUNFIRE FOR TROOP SUPPORT

Naval gunfire possesses many capabilities for troop support in landings which are not possessed by artillery. The principal advantages of naval gunfire support are:

1. The mobility of the firing ships enables them to select

the most advantageous lines of fire and range and to evade enemy counterfire. Mobility is one of the outstanding advantages of naval gunfire support.

2. The heavy caliber of guns available and their flat trajectory make them ideal for destruction of major defense installations, particularly those presenting vertical faces.

3. The high rate of naval gunfire, with power loading and mechanical ammunition supply, makes naval gunfire particularly suitable for neutralization missions.

4. The small deflection pattern of naval guns makes them valuable for close support of troops when the line of fire can be made parallel to the troop front line (enfilade fire).

5. Naval gunfire can be made available prior to and during as well as after the landing.

## LIMITATIONS OF NAVAL GUNFIRE FOR TROOP SUPPORT

There are limitations to the use of naval gunfire for troop support, but many of these can be overcome by judicious employment. Principally, the limitations are:

1. Effective naval gunfire for troop support requires observation of the fall of shot. Ships are unable to deliver effective fire unless the impact is observed by some agency.

2. Naval gunfire is limited by navigational factors which may not permit ships to occupy the most desirable positions for rendering fire support. Obviously, naval gunfire support is limited to those inland targets which are within the range of the guns.

3. Since the ship delivering support is in motion, continuous and accurate fixing of the firing ship's position for the delivery of fire on targets not visible from the ship is necessary.

4. Radio and visual communications between ship and shore are not as flexible or as reliable as communications by wire or telephone.

5. The flat trajectory of naval guns, while advantageous in some respects, renders fire on defiladed targets difficult. This limitation may be overcome, however, by the use of

reduced-velocity charges or by increasing the range to obtain a greater angle of fall.

6. The large range pattern of naval guns, as compared with artillery, requires that the line of fire be carefully selected when targets near our own troops are to be engaged.

7. The ammunition capacities of ships are so limited that the ability of any one ship to maintain uninterrupted support over an extended period of time is restricted. The amount of ammunition available for support is further limited by the necessity for the retention of a percentage of ammunition for possible air defense or surface action against enemy naval forces. This disadvantage may be overcome by providing adequate ammunition replenishment and by rotation of ships assigned to support missions.

## CLASSIFICATION OF FIRE

Naval gunfire may be classified in the manner shown in the following subparagraphs. It should be noted that the classifications are interrelated, and that in order to describe fully a particular type of fire it is usually necessary to employ terms from several different classification headings.

1. Effect sought:
   a. Destruction. Slow, deliberate, accurate gunfire delivered for the purpose of destroying a target, usually a material object.
   b. Neutralization. Rapid, fairly accurate gunfire delivered for the purpose of hampering, interrupting, or preventing enemy fire, movement, or action. The destruction of enemy installations is incidental in neutralization fire.
2. Tactical use:
   a. Close supporting fire. Gunfire delivered on objectives in the immediate vicinity of own forces (within 600 yards of friendly elements) to further their current efforts in that vicinity.
   b. Deep supporting fire. Gunfire delivered on objectives not in the immediate vicinity of own forces (over 600 yards from friendly troops) to further future efforts

in that vicinity or to reduce the effectiveness of the enemy in that area.

c. HARASSING FIRE. Sporadic gunfire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement.

d. INTERDICTION FIRE. Intermittent gunfire delivered on roads, road junctions, railroads, canals, rivers, airfields, or other channeled routes of communication to prevent free and uninterrupted use of them by the enemy.

e. PREPARATION FIRE. A heavy volume of prearranged gunfire delivered just prior to an attack by own forces on enemy positions.

f. COUNTER-BATTERY FIRE. Gunfire delivered against active enemy guns and fire-control stations for the purpose of silencing the guns.

g. ILLUMINATING FIRE. Gunfire, employing star shells, delivered to silhouette the enemy, aid observation, and facilitate own troop movements.

h. SCREENING FIRE. Gunfire, employing smoke projectiles, delivered to obscure the enemy's vision of friendly units and their deployment, movement or maneuvers.

3. Degree of prearrangement:

a. Prearranged or scheduled fire is gunfire that is formally planned and executed against targets of known location. Such fire is usually planned well in advance and is executed at a predetermined time or during a predetermined period of time.

b. Call fire is that delivered by fire-support ships at the request of troop units ashore. Call-fire missions must not be interrupted without permission of the unit requesting the fire, except in case of emergency.

c. Opportunity fire is delivered without any formal planning or troop request, on newly discovered targets, or upon targets of a transitory nature. Targets of opportunity may present themselves to the firing ship at any time, but fire must not be delivered without due regard for the safety of friendly troops. Ships delivering fire on targets of opportunity in close proximity to own troops require the approval of the troop echelon concerned before opening fire. Ships executing deep support missions must assure themselves that the target of opportunity is within their assigned sector of responsibility.

4. Technique of delivery:

   a. Direct fire is delivered on a target by using the target itself as a point of aim for either the guns or the director.

   b. Indirect fire is delivered on a target which is not itself used as a point of aim for laying the guns or the director. Direct fire is usually used on targets which can be seen from the firing ship; indirect fire is always used on targets not visible from the ship.

5. Type of fire:

   a. Area fire is that delivered in a prescribed area. Area fire is generally neutralization fire.

   b. Point fire is directed at a definite material target in order to destroy that particular object.

   c. Defilade fire (reverse-slope-fire) is delivered on targets located behind some terrain feature, particularly on a hill or ridge. Because of the flat trajectory of high-velocity naval projectiles, the hill or ridge may mask out the target.

   d. Enfilade fire is delivered on a target in such a manner that the range pattern of the fall of shot coincides with the long axis of the target.

## SELECTION OF THE WEAPON

The selection of the gun or weapon to be used in naval gunfire support is determined by the nature and size of the target to be engaged and by the proximity of friendly troops to the target. The 5-inch gun is normally used for close supporting fire; its rapid rate of fire and relatively small pattern size make it an excellent weapon for neutralization and destruction of targets immediately in front of advancing troops. Destroyers are usually assigned close supporting-fire duties because their maneuverability permits them to shift positions easily and quickly and to take positions close inshore for direct fire on targets in coastal areas.

Guns of 8-inch and larger caliber, with their great accuracy at long range, are normally reserved for deep supporting fire. The lethal bursting radii of projectiles from these guns limit their employment in close support. Moreover, ships mounting these guns (battleships and cruisers) are hampered in responding quickly to fire commands because they are less maneuverable than destroyers and their fire-control organization is more complex. The larger ships also have to carry out a number of additional duties. The destructive power of the projectiles of large-caliber guns makes them particularly effective against heavy installations ashore.

The 6-inch gun has qualities suitable for either close or deep support, but the light cruisers mounting these guns are better adapted for deep support use, since their maneuverability is restricted.

The 3-inch and 5-inch guns of DE's, APD's, DM's, and DMS's are suitable for harassing fire missions of the sort often executed against areas remote from our own troops, such as towns, harbors, and coastal air strips. The use of these ships for this purpose provides a necessary feature of support and releases ships with more accurate fire-control equipment for use where precision fire is required.

40-mm guns are effective for area neutralization where heavier-caliber guns are not required. The fire-control installation used with these guns is inadequate for indirect fire or safe close supporting fire. These guns are particularly effective against shoreline targets, especially enemy personnel in caves. When such fire is controlled by the dual-purpose gun directors, it is accurate and effective at short ranges; when not so controlled, larger safety limits with respect to proximity of own troops must be allowed.

The support of troops in landing operations has brought forth many new special weapons and specialized fire-support craft. The most important among these are:

1. The LCS. This converted LCI is equipped with fixed

launchers for 4.5-inch barrage rockets, which are effective up to 1,150 yards. The primary usefulness of this craft is beach neutralization, but it does carry automatic weapons in addition to its rockets, fitting it for other types of close-in gunfire support.

2. The LSMR. This is primarily a rocket ship; its main armament consists of launchers for 5-inch spin-stabilized rockets, the maximum range of which is about 11,000 yards. This craft can be used for deep support, harassing, and neutralization fire as well as for beach neutralization. Because it is equipped with a rocket fire-control installation, it can use its fire somewhat closer to own troops than the rocket LCS, which lacks this advantage.

3. Landing craft equipped with 4.2-inch mortars. Some landing craft and converted landing craft (including the LSMR's) are equipped with mortars which, according to the propellant used, can lob thin-walled high-explosive or white-phosphorus shells from 600 to 4,200 yards. Their greatest usefulness is beach and beach-flank neutralization during ship-to-shore troop movements, although the nature of mortar fire is such that it lends itself well to short-range night harassment. This is, of course, in addition to the primary function (high-angle defilade fire) of the mortar, which remains unaltered by the application of this typically land weapon to seaborne uses.

## SELECTION OF THE TYPE OF PROJECTILE

The selection of the projectile type to be used in support of troops depends upon the type of target and the effect sought on that target. High-capacity (HC) projectiles are designed especially for use in shore bombardment. They have a great explosive content at the expense of penetrative ability and produce a heavy blasting and shrapnel effect. HC is therefore suitable for neutralization or for destruction of relatively light installations. Antiaircraft common (AAC) projectiles are similar to HC projectiles in explosive and penetrative qualities. Their effective bursting radius of 35 to 50 yards makes them most satisfactory for close-support neutralization fire. Armor-piercing (AP) and common (COM) projectiles are designed to penetrate armor plate before detonating. Their use in shore bombardment is limited to fire on fixed enemy defenses such as concrete pillboxes and blockhouses which cannot be reduced by HC projectiles. White phosphorus (WP) projectiles have been found very useful for screening, incendiary, and antipersonnel effect. They may also be used as "identifying or marker shot" to identify salvos, to permit spotting when the impact burst is invisible due to foliage, or to give a prearranged signal to the troops supported. Illuminating (Illum) projectiles are used to provide illumination only.

The type of fuzes used with HC, AAC, and WP projectiles may be varied to meet different objectives. Mechanical time fuzes may be used to provide air bursts for maximum effect against personnel and light equipment. They should be set to burst 25 to 50 feet directly above the target. Proximity fuzes accomplish the same purpose with greater accuracy and less difficult fire control, as they compensate automatically for variations in ground elevation. Point-detonating fuzes, like proximity fuzes, require no advance setting but produce a lower and more concentrated burst, often desirable for demolishing equipment. Base-detonating fuzes are, of course, required whenever armored or other heavy structures must be penetrated.

## PHASES OF SUPPORT

It is convenient to divide the support for a landing operation into three general phases as follows:

1. Prelanding bombardment. This phase, which may commence well in advance of D-day, utilizes quick raids by surface ships to inflict damage and cause confusion, after which the ships retire. Similar strikes may be carried out by aircraft during this phase.

More often the bombardment group will move into position a few days prior to D-day and commence its schedule of prearranged fire which may continue right up to H-hour (the time of landing of the first wave of troops) or may be interrupted by retirement of the bombardment group for reasons of safety.

During this period, the effect sought by the bombardment is destruction of beach defenses, gun control and observation posts, or any defenses which could effectively oppose the landing. Slow, deliberate, close-range destructive fire is used whenever it is possible. In this, as well as in later phases, an attempt is often made to conceal the actual landing beaches by a schedule of fire covering other areas. The number of ships engaged in the prelanding bombardment, its duration, and the type of ammunition expended will depend upon such factors as the number of ships and planes available, the logistics (especially ammunition supply), and the nature of the terrain and its defenses.

In addition to its primary purpose of destroying designated targets which may hamper the landing, the force is often called upon to provide cover for minesweepers, underwater demolition teams, and hydrographic survey vessels. During the night it may engage in harassing fire to break down enemy morale. During the last hours prior to H-hour it may be called upon to provide interdiction fire to prevent assembly of reinforcements and their movements into the area of the landing beaches to man installations or repair damaged equipment. On D-day, prior to embarkation of troops, the bombardment of strong resistance points will be intensified. The force may be called upon to cover the final minesweeping operations and the approach of the attack force, especially the transports. When the transports are in position and the landing beaches are disclosed to the enemy, fire can be concentrated on strong points which intelligence reports or observation indicate have not been destroyed.

During this period, also, air-strikes are often scheduled to bomb and strafe the beaches. Provisions must be made to control fire so as to avoid hitting friendly planes.

2. Support during the landing. The primary missions of naval gunfire in this phase are to protect the transports while the landing force is embarking in boats, to silence

batteries which might destroy the assault waves as the boats move in to the beach, and to cover the actual landing of troops. The barrage must be lifted inland or shifted to the flanks as the troops near the beach to avoid hitting the landing force as well as to neutralize strong points from which destructive cross-fire could be poured on the beaches. In addition to close supporting neutralization fire on the landing and adjacent areas, deep supporting fire must be concurrently delivered to prevent enemy troop movement toward the landing area and to neutralize more remote opposing enemy defenses.

During the last few minutes, as the first wave nears the beach, a final air strike often parallels the beach, strafing and driving the enemy to cover. Also just before the landing, the rocket and mortar ships close inshore will deliver a devastating barrage, saturating the whole beach area.

The rapidity of events and general lack of information from troops being supported during and immediately following a landing require that most of the supporting fire be planned in advance, for delivery according to a carefully formulated and coordinated time schedule.

It is essential that close and deep supporting fire be scheduled to continue after the landing, in order to neutralize enemy opposition which would hinder the rapid establishment of organized troop units ashore. The postlanding schedule of fire must be carefully planned for coordination with the estimated troop advance ashore, but must be capable of quick modification to permit repeating, extending, or discontinuing any portion of the schedule when the advance differs from that expected. The duration of the scheduled fire after H-hour must extend well beyond the estimated time required to establish effective naval gunfire control agencies ashore.

In the case of heavily defended objectives, scheduled fire for close support must continue at least an hour after the landing, and for deep support at least 4 hours.

3. Support for troop advance ashore. Naval gunfire is employed after the landing phase to assist the advance of

troops to their final objectives. Close supporting fire from ships assigned to them, daily or upon special request, is made continuously available to troop units in assault. Deep support, including daily destructive fire missions, preparation fire for troop attacks, and night harassing fire, are scheduled for daily execution in fulfillment of troop requests. This phase of naval gunfire support commences upon the completion of the prearranged scheduled fire in support of the landing and continues until naval gunfire is no longer required for support.

## REQUIREMENTS, PRINCIPLES, AND TECHNIQUES OF EMPLOYMENT

### The Land-Target Problem

Naval gunfire against targets on land offers essentially the same problem as firing at a ship dead in the water, except for the following additional considerations:

1. As mentioned before, the geographical position of the firing ship must be continuously and accurately fixed, as from this are determined the range and bearing of the target in many instances when indirect fire must be used.

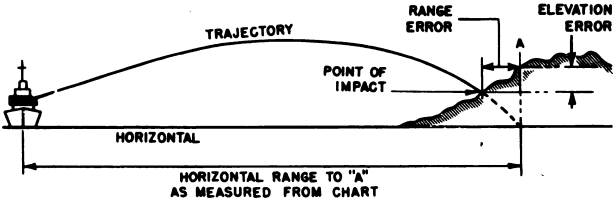


**Figure 11–1.—Errors resulting from failure to compensate for target elevation.**

2. Terrain features make correction of the fall of shot a difficult problem. Since range tables and rangekeeper solutions in main-battery systems assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be compensated for in the fire-control solution. Figure 11–1 illustrates the errors resulting when the range of a land target is taken from a chart and the target's elevation is not considered. When dual-purpose guns are used for

shore bombardment, the antiaircraft fire-control systems provide a ready solution to this problem. Terrain features also affect the size of the pattern in range; a forward slope decreases it, and a reverse slope increases it. Figure 11–2 illustrates these effects.

3. The set and drift of the current will affect the solution of the fire-control problem. When determined, drift may be entered into the rangekeeper or computer as target speed; the direction of the set is reversed and introduced as target course.

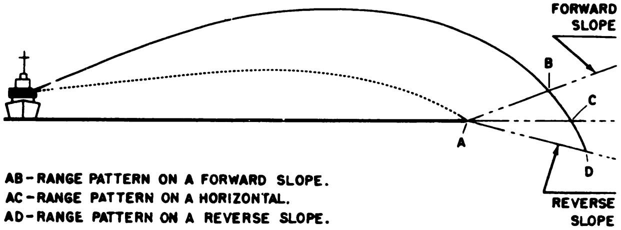

FORWARD SLOPE
B
C
A
D
AB-RANGE PATTERN ON A FORWARD SLOPE.
AC-RANGE PATTERN ON A HORIZONTAL.
AD-RANGE PATTERN ON A REVERSE SLOPE.
REVERSE SLOPE

**Figure 11–2.—Effect of terrain slope on the range pattern produced by ship's guns.**

4. In order to cover area targets more effectively with the shots of individual salvos, it may be desirable to increase the deflection pattern by setting the horizontal parallax correctors at infinity (i. e., removing horizontal parallax correction from the gun battery).

5. Frequent and rapid changes in the targets to be engaged require ready accessibility of various types of ammunition and fuzes.

## Principles of Employment

Effective support of troops by naval gunfire is dependent on certain principles of employment and techniques of delivery of that gunfire which might be called tricks of the trade. The following paragraphs briefly discuss these. Prerequisites of effective support are the proper alinement of the fire-control system and gun battery, rapid and reliable internal and external communications, and well-trained ship control, fire control, and gun control personnel.

The primary duty of naval gunfire in all phases of the support is the immediate and effective silencing of heavy enemy weapons which open fire on our forces. It is essential that a counter-battery plan satisfying all contingencies be kept in constant readiness and that fire-support ships be ready and alert at all times for the delivery of this fire. When the source of enemy fire is not known, heavy counter-battery fire on suspected sources is delivered pending the determination of the exact location of the enemy battery. The whereabouts of friendly forces must be kept in mind during such an attack.

Only by thorough familiarity with the land areas assigned, achieved through repeated firing, observation, and analysis, can the most effective fire be delivered by ships. The shifting of ships to different areas of responsibility, or frequent shifting of fire between targets widely separated in the same general target area, is avoided.

Unlike surface or air actions at sea, naval gunfire support requires moderately low speeds. The use of high speed in a firing ship requires it to make frequent course reversals in order to remain in its assigned sector, results in unacceptable inaccuracies in establishing the ship's position for indirect fire, takes the ship too quickly beyond effective firing positions limited by terrain features, and may result in prohibitive interference with other activities offshore. A low speed is usually selected which will allow good control of the ship and the supporting fire, consistent with the tactical situation and the submarine menace. If necessary, the ship will lie to or anchor, maintaining desired heading by the use of the engines. Best results for indirect fire will be obtained if ships steam on a steady course at a constant low speed.

Direct fire is employed whenever possible, although indirect methods must always be employed when visible points of aim are not available. Indirect fire requires more ammunition and time than direct fire for equally destructive success. It requires air or ground observation of the fall of shot in order to ensure hits on point targets. The effectiveness of naval gunfire is increased by the employment of an air spotter working with a ground spotter.

Once established, the maintenance of the hitting gun range and deflection is essential to effective destructive fire. Periods of continuous slow fire with reduced salvos are therefore preferable to more rapid fire interspersed with relatively long nonfiring intervals. Furthermore, the shifting of fire between widely separated targets is kept to a minimum.

The decisive destruction of heavy defenses is greatly enhanced by very close-range, slow, deliberate, direct fire against such installations. Fire-support ships usually operate as close inshore as safe navigation, the tactical situation, enemy shore batteries, and the type of fire required will permit.

Close supporting neutralization fire on the landing area in support of troops about to land, although scheduled to be shifted therefrom on a time basis relative to the estimated time of H-hour, must be adjusted according to the actual position of the troop landing craft. From reports of landing-craft progress received, but primarily from own observation when possible, fire-support ships individually determine when their fire is about to endanger troops nearing shore, and accordingly shift the fire from the landing area.

Close cooperation between ships and the troop units to which assigned for support is essential for maximum effectiveness. Interchange of information between supporting ships and troop units results in more intelligent and effective fire support. Of particular importance in this connection is the safety requirement that all fire-support ships maintain an up-to-date plot of own troop front-line positions as periodically announced by elements of the landing force. This not only prevents endangering own troops, but permits selection of the most suitable line of fire with respect to troop lines. Another consideration is the necessity for safeguarding friendly aircraft operating in the area.

Illumination of land areas by naval star shells is effective in preventing enemy counterattacks, infiltration, and the movement of enemy troops at night. Its morale-boosting effect on our own troops generally results in requests for exorbitant star-shell expenditures to produce unnecessary illumination of the land area throughout the night. Except during actual enemy counterattacks, star shells fired at a reduced rate and at irregular intervals normally discourage enemy movement. Maximum benefit from the limited supply of star shells available requires judicious control and coordination by troop units to avoid silhouetting of own forces ashore and afloat. When delivering illumination fire, the line of fire must be so adjusted with relation to our front lines that friendly troops are not endangered by star-shell bodies. Except in rare instances, searchlight illumination for troop support is generally unsuccessful; it almost invariably draws enemy fire on the ship employing it.

## REQUIREMENTS FOR NEUTRALIZATION

The volume of fire required for neutralization of an area is difficult to establish. The standard volume established prior to World War II prescribed the equivalent of sixteen 75-mm projectiles per minute per 100-yard square as being sufficient for neutralization. Although the experiences of World War II showed this to be entirely inadequate in many instances, it is still a valuable guide which may be modified as conditions dictate. Experience proved that the blast effect of bursting projectiles had been highly overrated in neutralizing effect; it was found instead that neutralization primarily depended upon the casualties produced or threatened by flying fragments. Fragmentation effects vary greatly, even in the case of projectiles which are identical, because they depend upon such factors as angle of fall and terminal velocity. For example, the number of casualties inflicted may double with an increase in angle of fall from 10° to 60°. The effectiveness of fire for neutralization will also vary in accordance with the terrain, the types of enemy installations, and the quality of the enemy troops. Extensive studies of neutralization effects in World War II are being made in an effort to establish a new and more accurate neutralization factor.

## TARGET INTELLIGENCE

Before undertaking any bombardment of land targets, a thorough familiarity with the terrain and hydrographic features of the objective, and with the location of profitable targets, must be acquired. The study of available charts, maps, aerial photographs, radar PPI simulations, mosaics, and other pertinent information will be necessary for rapid, effective troop support. Normally these charts, maps, photographs, and target information will be furnished each fire-support ship prior to the operation. The systematic destruction of defenses requires the continuous assembly and evaluations of targets known beforehand, and for those discovered in the course of the operation. Damage assessment must be based upon visual observation and photo-analysis. A common error is over-optimism as to the effectiveness of naval fire against land targets.

## TARGET LOCATION DESIGNATION

Rapid and accurate means for designating the location of targets is an essential feature of naval gunfire support. It should be obvious that the troop unit supported and the supporting ship must use a common map. Although they need not be of the same scale, and seldom are, the target maps must be identical regarding terrain features and the method of locating points thereon. Like other techniques of naval gunfire support, the development of a system of target location designations has passed through several stages, following generally a grid-system method. In this method, the land and sea areas at the objective are divided into squares by north-south and east-west lines, which are numbered. These lines are called grid lines.

One grid system of target designation for naval gunfire support is called the WORLD GRID. (See fig. 11–3.) It divides the surface of the earth into squares of 1,000 meters (or yards) on a side. These squares are numbered according to the numbers of the grid lines which cross at the lower left-hand (southwest) corner of the square; the west side grid number is given first, followed by the south side grid number. Square 4320 is, then, the square at the southwest corner of which vertical grid line 43 crosses horizontal grid line 20. For convenience in designating smaller areas, these 1,000-meter squares are further subdivided into 25 squares of 200 meters on a side. These 200-meter squares are lettered from *A* to *Y* inclusive, beginning with the upper left-hand (northwest) corner of the 1,000-meter square.

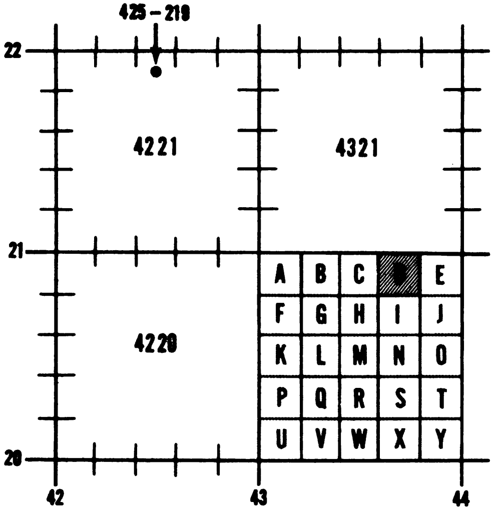


Figure 11–3.—A portion of the world grid.

Two methods of target designation are available when using the world grid, one of which is used to designate an area, the other an exact location (point target). For area designations the number of 1,000-meter squares is designated, followed by the letter indicating the smaller area in which the target is located. Thus given a designation "Target at 432*D*," a fire-support ship will endeavor to place the mean point of impact of the initial salvo in the center of 200-meter square *D* of 1,000-meter square 4320.

For point target designation a decimal system is used. The decimals are based on the numbers of the grid lines in such fashion that a point half-way across from line 42 to line 43 and nine-tenths of the way up from line 21 to line 22 may be designated as 425–219.

Fire-support ships are provided with approach charts and bombardment charts for use on their dead-reckoning tracers. These charts are complete in hydrographic as well as topographic detail, and both have a grid system overprinted on them. These charts are of particular use in the delivery of indirect fire, and will be discussed later.

## THE SHIPBOARD PROBLEM OF NAVAL GUNFIRE SUPPORT

### Direct Fire

Targets which are visible from the firing ship offer the simplest fire-control problem to the ship, and their destruction is easier than those targets which require indirect fire. When the target can be seen, the director can furnish accurate target bearing and elevation. These, with a present range which can be measured, ensure an accurate fire-control set-up which should result in early hits. Direct fire is controlled as it would be for fire against enemy ships except that (1) at short ranges better accuracy may be obtained if the gun pointers control gun elevation and firing, and (2) when the ship is providing call fire support, the fire will be directed, controlled, and spotted by the shore spotter.

### Indirect Fire: Use of the Bombardment Chart

Given an accurate bombardment chart, and knowing the exact position of own ship, it is possible to measure off range and bearing to any land target that has been designated in advance and to hit the target without using directors or rangefinders.

The ship's position is accurately determined by navigational methods, using positively identified landmarks, and is plotted on the bombardment chart. Since own ship's course and speed are known, future positions may be projected ahead along the ship's track by dead reckoning. A future position, usually one minute ahead, is chosen, and from this point bearing and distance to the designated target are picked off the chart. These values of target range and bearing, together with own ship's course and speed, are set into the rangekeeper or computer which is being used to generate the solution. Target speed is set on zero. During this period, the time motor is off. When the ship passes through the position chosen, "Mark" is given by the plotter and the time motor of the computer is turned on. The computer should now generate present values of target range and bearing that agree with the actual measured values. These values, together with a fixed setting of altitude, based on the actual height of the target, are used to make up gun orders to hit the target. At stated periods, usually every minute after the initial set-up, "Mark" is given and the computed values are compared with the measured values. If they do not agree, since the target is motionless, the error must be due to some factor affecting the position of the ship. The set and drift of the current will cause such variation, and corrections for this effect may be compensated by introducing the drift and set of the current as target speed and reverse target course respectively. At any time after the computed solution agrees with the measured values, the initial ballistic can be applied, and fire opened on the unseen target.

### Indirect Fire: Point OBOE Method

This method of indirect fire was devised primarily for older ships with fire-control systems and rangekeepers incapable of correctly generating range and bearing to a designated grid point. Its use, however, even by the newest ships is advantageous under certain conditions such as when no shore spotter or air spotter is available for observing the fall of shot. The method requires a visible point of aim (designated "Point OBOE") near the target, as well as the accurate location of the target and Point OBOE on a map.

In practice, the director line of sight is kept continuously trained and ranged on the point of aim (Point OBOE) to give a continuous range and bearing solution to this point. Salvos are initially fired at Point OBOE as a check on the gun ballistic, and as soon as the mean point of impact has been spotted to hit, range and deflection spots necessary to hit the invisible targets are applied. Point OBOE should be selected so that the limits of the spot dials do not have to be exceeded to reach desired targets.

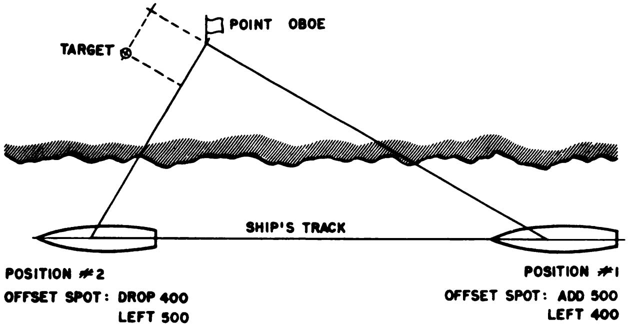


Figure 11–4.—Point OBOE method of indirect fire, showing necessity for continuous changes in offset spot to hit target.

Since the motion of the firing ship continuously changes the values of the offsets from the point of aim, frequent changes in these offset spots must be made to ensure hitting the target. This problem is illustrated in figure 11–4. One way to determine correct range and deflection spots continuously is to use a small transparent overlay on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on Point OBOE, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.

### Indirect Fire: Functions of CIC

The primary function of CIC in naval gunfire support is to keep an exact check upon the ship's position and from this to determine ranges and bearings to targets designated for indirect fire. It can be readily appreciated that the accuracy of fire, when using the method previously described, depends primarily on the skill of the CIC team. CIC also keeps a record of own troop front-line positions, target locations, and other information pertinent to the support of the troops ashore. It acts as the clearing house for information to and from the shore fire-control party and air observer, with whom it has direct voice radio communication. Thus in naval gunfire support, CIC keeps the ship's commanding officer, gun control, and plot advised regarding the requirements for support, furnishes the information necessary to provide the support, and gives the shore fire-control party such information as may be necessary or useful. In addition to target range and bearing, CIC must determine, from contour lines of the bombardment chart, the elevation of the target above sea level and send this to the plotting room so that range error resulting from this elevation may be corrected in the computer.

On heavy ships (battleships and cruisers) the above functions of CIC are often performed in a section of the plotting room. This leaves the ship's CIC free for the other vital duties it must perform.

## SPECIAL FIRE-CONTROL PROBLEMS OF NAVAL GUNFIRE SUPPORT

Targets which are located on the far slope of a hill or similar terrain feature lying between the firing ship and target present a particularly difficult problem to the flat trajectory of naval gunfire. This problem (defilade fire) requires obtaining an angle of fall which will clear the crest of the hill and be steep enough to hit the target beyond. When this situation occurs, the angle of fall is chosen which is greater than the angle of the reverse slope. Two solutions are then available. The ship may either increase the range to obtain

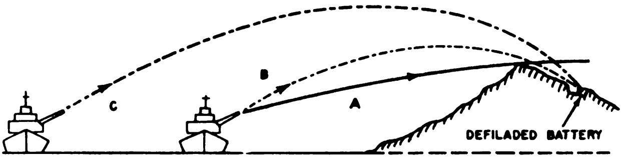


Figure 11–5.—Problem of hitting a defiladed target.

the angle of fall selected, or it may use reduced-velocity charges at the shorter range to obtain this selected angle of fall. In figure 11–5, which illustrates this problem and its solutions, *A* is the trajectory produced by standard service charges and is too flat; *B* is the trajectory which can be obtained by using reduced-velocity charges; *C* is the trajectory which can be obtained with standard service charges by increasing the range.

In the event it is necessary to fire over friendly troops occupying an elevated position between the firing ship and the target, it is necessary to determine the elevation of the target, the elevation of the troop position, and the differences between the two. Call this difference $y$, and the horizontal distance between the troop position and the target $x$. By referring to trajectory curves, you can determine the range at which the abscissa $x$ yards from the point of impact is safely greater than the difference in elevation $y$. This is the limiting range outside of which it is safe to fire.

## SPOTTING BY TARGET GRID SYSTEM

Spotting, as it applies to naval gunfire in general, was discussed in chapter 10. All the general principles contained therein apply in shore bombardment spotting, but additional considerations apply also, especially when spots are to be made by a shore fire-control party.

A spotter ashore must be advantageously located to observe the fall of shot. In most cases this requires that he be as close as possible to the enemy positions which will have to be taken under fire; this presents him with a very serious front-line problem of survival. During World War II snipers' bullets were often very effective in curtailing the observation by shore spotters.

Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and target (called the gun-target line). Spots made from aircraft can be oriented readily to the gun-target line, since both the gun and the target are normally within the aircraft observer's field of vision. But spotters ashore are frequently unable to see the firing ship and, so long as they are required to make their reports in relation to the gun-target line, this seriously limits the value of the information sent by the spotter to the ship. Unless the spotter is located along the gun-target line (which is seldom if ever the case), it becomes necessary for him to plot the gun-target line on his grid chart. This necessitates that he be informed of the firing ship's bearing from the target, and that he possess sufficient plotting equipment to locate himself with respect to the gun-target line. Frequently errors in spotting are introduced under this system from such improper orientation of the spotter with reference to the gun-target line.

To simplify this problem for the spotter, the Army Artillery School at Fort Sill developed the target-grid system for use in spotting the fall of shot on land. As a result of trials in joint exercises, the target-grid system has been incorporated into the Standard Spotting and General Shore Bombardment Procedure for use within the naval service.

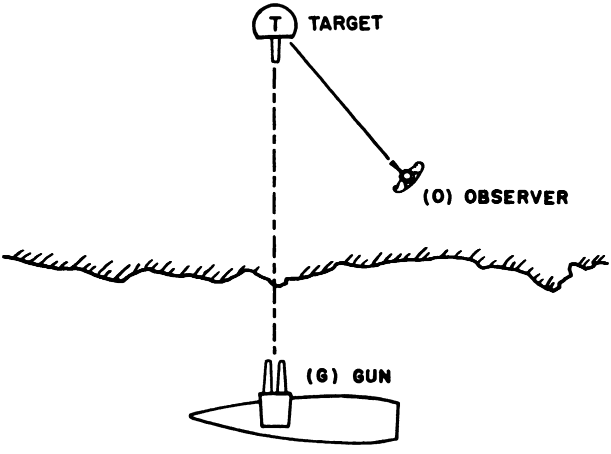


Figure 11–6.—Target-grid spotting problems.

The objective of this system is to permit the observer to spot the fall of shot just as he sees it along his own line of sight to the target, called the observer-target line, irrespective of the position of the firing ship and of the gun-target line.

The procedure is briefly outlined as follows (refer to fig. 11–6):

1. The observer, in his initial fire request, must give the azimuth from himself to the target; direction OT in the illustration.

2. The observer makes all his observations and corrections with respect to the observer-target line (OT).

3. The fire-control party aboard ship converts the corrections of the observer to corrections with respect to the gun-target line (GT).

4. The fire-control party introduces into the rangekeeper the spots corrected to the gun-target line, rather than the observer's uncorrected spots.

## GRID SPOT CONVERTER

A typical grid spot converter, as shown in figure 11–7, consists of two concentric plastic disks. The bottom disk is the larger and is graduated on its outer edge (outside of the periphery of the smaller disk) in degrees in a manner similar to a compass card, except that the graduations are counterclockwise. The top, or smaller, disk is graduated at its outer edge in mils from zero counterclockwise through the complete circle back to the point of origin, or through 6,400 mils.

The top disk is movable relative to the bottom disk at a pivot point at their common center. Etched on the under side of each disk are parallel lines about a half-inch apart, running north-south and east-west; each disk has an arrow at the zero graduation.

The converter is used as follows:

1. The converter operator should have continuous access to (*a*) own ship's generated target bearing and (*b*) the spots from the observer. The plotting room is considered the most acceptable station for the converter operation.

2. As previously stated herein, "The observer, in his initial fire request, must give the azimuth from himself to the target." The top disk is marked with grease pencil at the point in mils corresponding with the true azimuth in mils

given by the spotter. The top disk is then rotated until it matches with the generated true bearing from the ship to target on the bottom disk.

3. The fall of shot is plotted on the top disk, using the center as the target (or point of departure). A grease-pencil dot is placed to right or left of the line joining the center and the arrow on the top disk an amount equivalent to deflection error and above or below the center (along a line parallel to that from the center to the same arrow) an amount equal to the range error.

4. The point marked on the top grid with grease pencil is used to determine the corrections in deflection and range which must be applied. This is done by measuring the distance the plotted point is from the center, using the coordinates of the lower disk. The distance perpendicularly away from and to right or left of the arrow on the lower disk and the distance from the center parallel to the same arrow will indicate the fall of shot with respect to the gun-target line. From this the required spots can be obtained.

5. The point plotted for each spot is erased after range and deflection have been determined, in order to be ready for the next spot. The mark made to indicate spotter's azimuth is retained and used for succeeding spots, unless another azimuth is given by the spotter or unless firing is shifted to another target.

6. Although the spotter is required to indicate altitude of targets and to make spots in altitude as may be required, the converter is not involved in altitude spots.

An example will clarify the use of the grid spot converter. Refer to figure 11–7. Assume an observer-target line of 1,500 mils (true) and a gun-target line of 140° true. A mark a made with a grease pencil at 15 on the top circle, representing the observer-target line bearing 1,500 mils (true). The top disk is then rotated until this 15 mark lines up with the 140 mark on the lower circle (the bearing of the gun-target line). The arrows on the converter then give a picture of the intersection of the gun-target line and observer-target line at the target, which is pictured at the center. Assume that

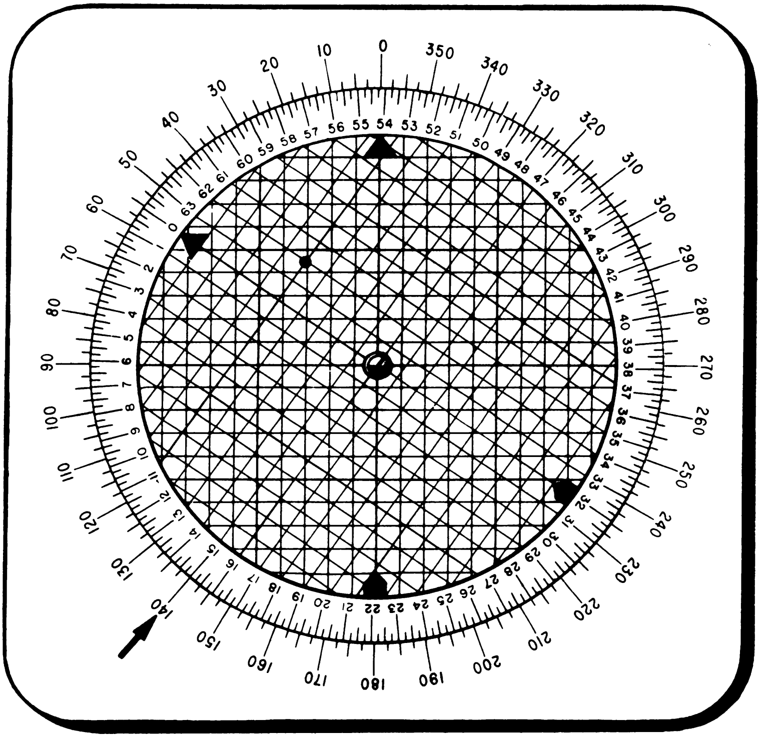


Figure 11–7.—Grid spot converter.

a salvo has been fired and that the spotter has sent back a spot of LEFT 200; DROP 500. Upon receipt of this spot, in the plotting room aboard ship, it is plotted with respect to the observer-target line as shown by the dot on the top disk (since the spotter has spotted with reference to this line). Then, by referring this dot to the gun target line (the lower disk), the proper spot to apply, in this case RIGHT 300; DROP 450, is picked off the grid converter.

## QUIZ

1. Describe briefly the mission of naval gunfire in aid of landing operations.
2. Name one of the outstanding advantages of naval gunfire support.
3. When can naval gunfire be made available?
4. What is destruction fire?
5. What is harassing fire?
6. When is call fire delivered?
7. What is the difference between direct and indirect fire?
8. What determines the selection of gun or weapon to be used in naval gunfire support?
9. Why are destroyers usually assigned the duties of close supporting-fire?
10. Why were high-capacity (HC) projectiles designed especially for use in shore bombardment?
11. What are the three general phases of support?
12. How do terrain features affect the size of the pattern in range?
13. How are drift and set of the current entered into the rangekeeper?
14. What do the large squares represent on the World Grid?
15. Using the Point OBOE method of indirect fire, when are the range and deflection spots necessary to hit the invisible target applied?
16. What is the primary function of CIC in naval gunfire support?
17. What are the two solutions to the problem of hitting a defiladed target?
18. Why was it necessary to develop the grid spot converter?

# CHAPTER 12

## THE DUMMY DIRECTOR AND ERROR RECORDER—TEST EQUIPMENT

Any striker who can use the proper tools can repair a greater percentage of the casualties to fire-control equipment. But first a casualty must be pointed out to him and the repair procedure outlined by someone who knows the theory behind the equipment and how to use testing devices.

Casualty analysis is usually done by an experienced Fire Control Technician who will check the computations of each subassembly and locate the casualty in the particular section in which it occurred. Then, with a few simple tests, he will quickly identify the trouble—whether an adjustment has slipped, a resistor has changed value, the collector rings of a synchro have become corroded, or some other casualty has occurred.

Before 1938, Fire Controlmen got along with the minimum of test instruments—the megger, the standard motor, the dial indicator, and the gunner's quadrant. But the development of radar and electronic computers called for new types of instruments, and today no Fire Control Technician can make a complete casualty analysis without some of the following:

Power analyzer.
Vacuum tube and analyzer.
Ammeter.
Volt-ohm-milliammeter.
Electronic-volt-ohm-milliammeter.
Ohmmeter.
Megger.
Oscilloscope.
Stroboscopic tachometer.
Condenser tester.
Neon lamp tester.
Dummy director.
Error recorder.
Signal generator.
Gunner's quadrant.
Dial indicator.

Fortunately, several of these instruments are often combined to form a single, portable unit called a MULTIMETER or MULTITESTER. But even with this reduction in numbers, most ships do not carry a complete inventory of test equipment. Only on repair ships and tenders are all of these instruments available.

You are already familiar with the vacuum-tube-volt-ohmmeter and the oscilloscope. The standard motor is discussed under the third class qualifications and the dial indicator under the qualifications for second. Since it is not practicable in this training course to cover all of the instruments listed above, the dummy director, error recorder, gunner's quadrant, radio receiver analyzing equipment OE–12, and vacuum tube tester have been selected as typical of the instruments required for routine maintenance work. In all cases, it must be remembered that the best way to learn to use testing instruments is by actual practice.

## DUMMY DIRECTOR AND ERROR RECORDER

Before 1938, the transmission and follow-up systems of guns and directors were tested only for alinement with all the units of the system at rest. But the director and guns are always in motion when following a moving target, and it is important that they be in alinement not only when stationary but when moving in response to a dynamic signal as well. Thus it became necessary to determine the accuracy with which a director or gun responds to a continually changing signal, such as generated bearing or gun orders. The dummy director and error recorder were developed for this purpose; they provide a means for transmitting an automatic signal to a gun or director and simultaneously measuring the amount that the gun or director lags the signal. These tests are called dynamic accuracy tests.

The first dummy directors and error recorders were issued only to naval shipyards and repair ships, but the newer models are standard equipment in the plotting rooms of most combatant ships.

The dummy director introduces angular motion electrically into the system under test—either constant velocity motion or simple harmonic motion. The error recorder makes a record of the test in the form of a time-displacement curve. The curve indicates the difference between the signal to the mount and mount response.

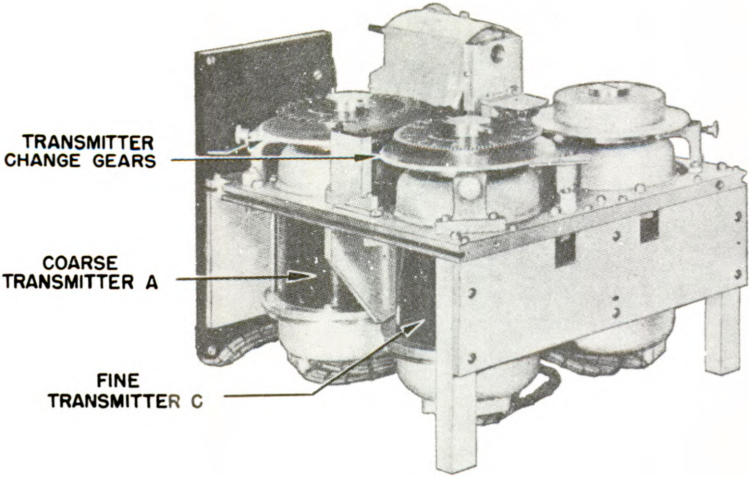
To test a director, gun, or turret in remote control, electrical signals (corresponding to either a constant velocity or a simple harmonic motion of the mount) are transmitted from the dummy director to the remote control equipment at the mount and to the error recorder. The error recorder also receives a signal corresponding to mount response from the gun or director under test. As the mount moves in response to the changing signal, the error recorder makes a permanent record of the instantaneous difference between mount order and mount position. The magnitudes of the errors in mount position are determined by measuring (from a reference line) the displacement of the curve produced by the error recorder. Transparent scales are supplied with each recorder for this purpose.

The curves obtained from a dynamic accuracy test should be compared with the curves taken when the equipment was accepted by the Bureau of Ordnance. If the curves from the periodic tests show rough follow-up action or a response lag in excess of that specified for the particular mount, the power drive should be checked for malfunctioning. The controls should be adjusted to bring the dynamic accuracy tests within allowable limits of error.

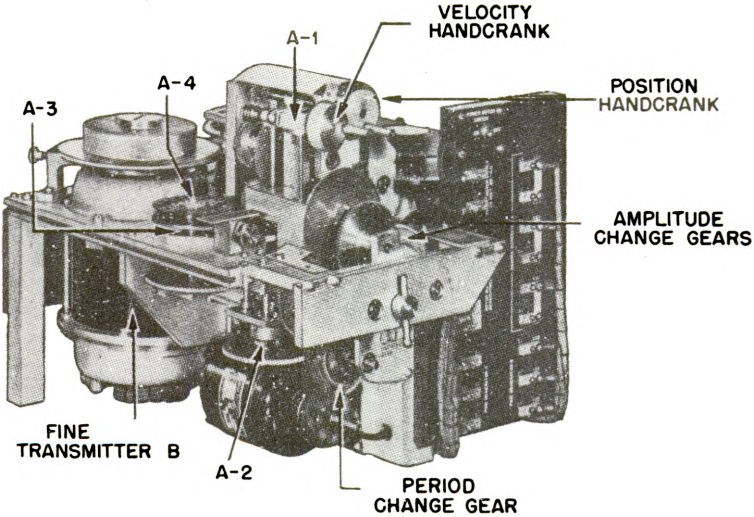
## THE DUMMY DIRECTOR MK 1 MOD 3

The Dummy Director Mk 1 Mod 3, shown removed from its case in figure 12–1, is designed to transmit electrical orders simultaneously to three synchro circuits. The output of the synchros—depending on the gear ratios selected—is as follows:

1. The output of coarse transmitter *A* is proportional to 720°, 360°, 240°, 180°, or 100 seconds fuze setting time per revolution.



RIGHT SIDE AND REAR



LEFT SIDE AND FRONT

Figure 12–1.—Dummy Director Mk 1 Mod 3 removed from its case.

2. The output of fine transmitter *C* is proportional to 10°, 5°, 2.5°, or 2 seconds fuze setting time per revolution.

3. The output of fine transmitter *B* is always proportional to 10° per revolution.

Figure 12–2 is a schematic diagram of the dummy director. Refer to it throughout the following discussion. The three principal parts are the power motor, component integrator, and synchro transmission system.

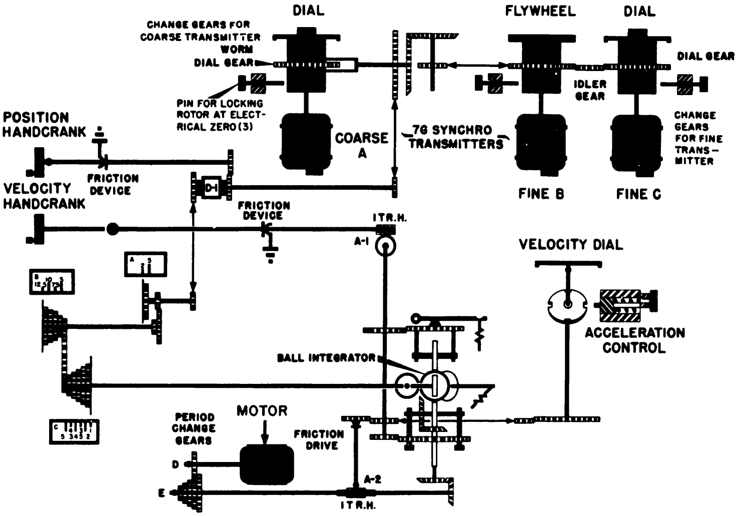


Figure 12–2.—Dummy Director Mk 1 Mod 3 gearing diagram.

The power motor is a constant velocity motor of the synchronous type. The synchro transmitters are size *7G*. The component integrator is a standard ball-type integrator. Notice that only the output of the cosine shaft of the integrator is used.

The motor turns both inputs to the component integrator. If the axis of the driving roller is held at a fixed angle, while the driving roller is rotated, the velocity of the output is constant. If both the driving roller and the axis of the driving roller are turned at a constant speed, the velocity of the output varies sinusoidally.

The output shaft of the integrator drives through two sets of change gears and *D*–1 to the rotors of the synchro transmitters. (The voltages generated in the secondary windings of these synchro units are the outputs of the dummy director.) The rotors of the synchro transmitters can also be turned by the handcrank input to *D*–1. A friction device on the shaft prevents the output of the integrator from backing out through the handcrank.

When a sinusoidal signal is required, worm gear *A*–1 is disengaged and the detent of the acceleration control is moved clear of the detent plate. The period of the signal is determined by installing a gear of the proper size on the power motor shaft. The size of the gear governs the speed of rotation of the axis of the integrator driving roller about the axis of the integrator output shaft. Gears for 4.44-, 9-, 12-, 18.8-, 31.2-, and 60-second periods are provided with each dummy director. The amplitude of the period is controlled by the change gears between the integrator and the synchros. The signal oscillates about a reference point selected by the handcrank.

When a signal of constant velocity is required, the axis of the driving roller held at a fixed angle with respect to the axis of the output roller by either engaging gear mesh *A*–1, or by engaging the detent of the acceleration control. When prolonged tests at constant velocity are conducted, excessive wear of the friction drive can be avoided by slipping clamp *A*–2.

The signal velocity is adjustable between zero and maximum (determined by the period and amplitude change gears) by engaging *A*–1 and turning the velocity handcrank. The velocity of the output can be checked by timing the rotation of the fine dial.

If the detent lock is used instead of *A*–1, the signal velocity can be varied only by the period and amplitude change gears, because the detent locks the axis of the driving roller at either zero or maximum velocity position.

The axis of the driving roller should always be set for zero velocity before starting the power motor. Thus excessive acceleration of the signal is avoided.

The gear ratio between coarse transmitter $A$ and fine transmitter $B$ may be altered by changing both the gear mounted on the rotor of the coarse transmitter and the worm that drives it. Similarly, the gear ratio between fine transmitter $C$ and fine transmitter $B$ may be altered by changing the gear mounted on the rotor of fine transmitter $C$ and the idler that drives it.

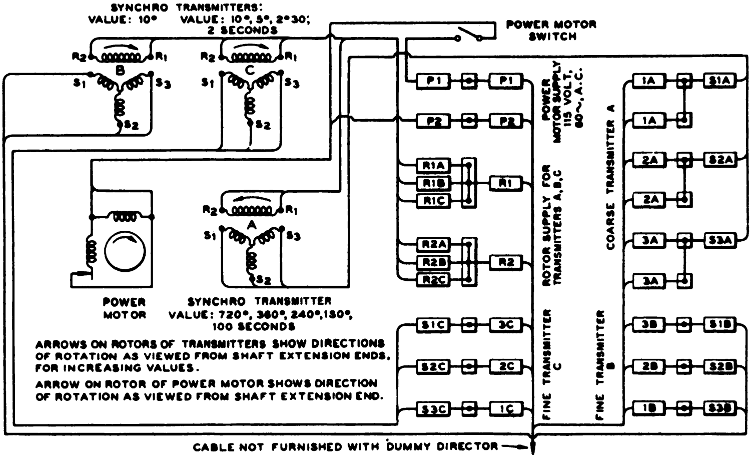

SYNCHRO TRANSMITTERS:
VALUE: 10°
VALUE: 10°, 5°, 2°30', 2 SECONDS
R2
R1
B
S1
S3
S2
R2
R1
C
S1
S3
S2
POWER MOTOR SWITCH
R2
R1
A
S1
S3
S2
POWER MOTOR
SYNCHRO TRANSMITTER VALUE: 720°, 360°, 240°, 180°, 100 SECONDS
ARROWS ON ROTORS OF TRANSMITTERS SHOW DIRECTIONS OF ROTATION AS VIEWED FROM SHAFT EXTENSION ENDS, FOR INCREASING VALUES.
ARROW ON ROTOR OF POWER MOTOR SHOWS DIRECTION OF ROTATION AS VIEWED FROM SHAFT EXTENSION END.
P1
P1
P2
P2
R1A
R1B
R1C
R1
R2A
R2B
R2C
R2
S1C
3C
S2C
2C
S3C
1C
POWER MOTOR SUPPLY 115 VOLT, 60~, A.C.
ROTOR SUPPLY FOR TRANSMITTERS A, B, C
FINE TRANSMITTER C
COARSE TRANSMITTER A
FINE TRANSMITTER B
1A
S1A
1A
2A
S2A
2A
3A
S3A
3A
3B
S1B
2B
S2B
1B
S3B
CABLE NOT FURNISHED WITH DUMMY DIRECTOR

Figure 12–3.—Dummy Director Mk 1 Mod 3 wiring diagram.

Figure 12–3 is a schematic wiring diagram of the Dummy Director Mk 1 Mod 3.

## DUMMY DIRECTOR MK 3 MODS 0 AND 1

The Dummy Director Mk 3 all Mods is an improvement over the Mk 1 Mod 3. It consists of three synchro transmitters driven by a control mechanism in either simple harmonic (SHM) of constant velocity motion (CVM), at variable amplitudes.

Synchros $A$ and $C$ (type $6G$) transmit electrical angular motion to the equipment under test, while synchro $B$ (type $5G$) supplies a signal to the differential of the error recorder (fig. 12–4).

A motor of 7 r.p.m. turns synchro transmitter $1G$ through

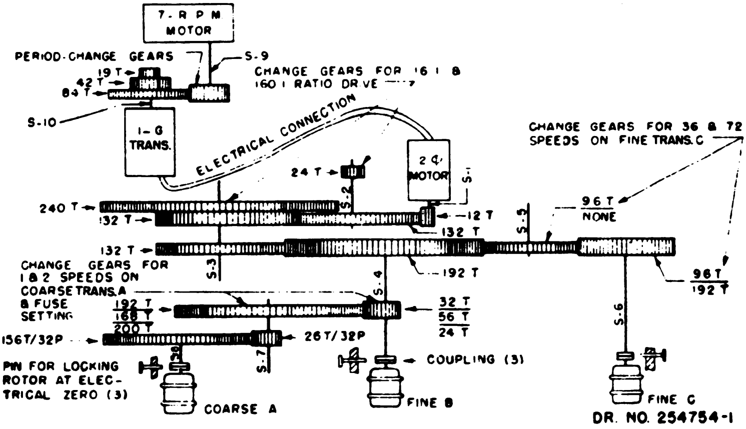


Figure 12–4.—Dummy Director Mk 3 all Mods gearing diagram.

the change gears on shafts 9 and 10. The speed of rotation of the 1*G* controls the period of SHM. Periods of 2, 4, 5, 6.9, 9, 11.8, 13.1, 14.7, 18.1, 23.6, and 29.4 seconds can be obtained by substituting the proper gears on shafts 9 and 10 (fig. 12–4).

The single phase armature winding (*R*1 and *R*2 of the 1*G*) is energized through the "on-off" toggle switch *SW*–1 (fig. 12–5). Only one phase of the three-phase output of the 1*G* is used. This voltage, whose amplitude and polarity vary as the sine of the angular displacement of the rotor, is impressed on terminals 2 and 4 of the variac whenever *SW*–2 is in the SHM position. Condenser *C*–2 is inserted to counteract the lag in current caused by the high inductance of the field winding of the 1*G*.

The contact arm of the variac is turned by the amplitude control knob mounted on the armature shaft. The position of the arm is read on a dial mounted beneath the control knob. The dial has two scales. The top scale (fig. 12–8) is calibrated in degrees of constant velocity per second, while the right-hand scale is graduated for the amplitude of the SHM.

The output of the variac, between the fixed center contact

1 and the movable contact 3, is impressed across the variable field winding *Fv* of motor *M*–2, in series with a reference voltage from the secondary of transformer *T*–2. The primary of *T*–2 (fig. 12–5) is energized from the field winding of synchro generator *A* through *SW*–3 and *SW*–4. Condenser *C*–3 serves the same purpose as *C*–2.

Reference selector *SW*–4 selects the phase and polarity of the output of synchro *A*. Thus six reference points—each 60° apart—about the reference circle are available.

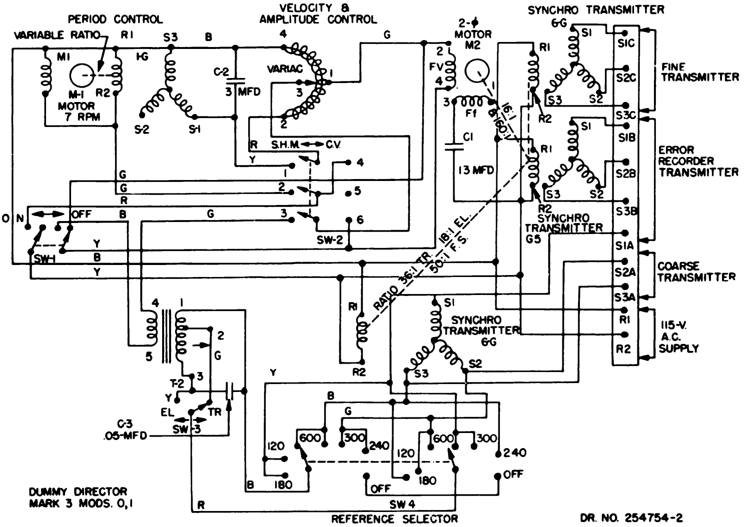


Figure 12–5.—Schematic wiring diagram of Dummy Director Mk 3 Mods 0 and 1.

The current through the fixed field winding *Ff* of *M*–2 leads the applied voltage by 90° as the result of the 13 mfd. condenser *C*–1 in series with the winding.

The output of *M*–2—reduced by the 1:16 gear ratio on shafts 1, 2, 3, 4, 5, and 6—turns the rotors of fine synchros *B* and *C*. Shaft 4 also turns the rotor of *A* through shafts 7 and 8. The ratio between *B* and *A* is 18:1 for an elevation signal and 36:1 for a train signal.

A removable flywheel on shaft *S*–1 smooths the operation and eliminates sudden accelerations of *M*–2.

When *SW*–2 is in the *CV* position (fig. 12–5), the output of synchro 1*G* and transformer *T*–2 are replaced by the 115 volt supply at terminals 2 and 4 of the variac. By adjusting the variac, the speed of *M*–2 can be regulated in either direction. The velocity of the motor is read in degrees per second on the *CV* portion of the dial.

## THEORY OF OPERATION OF THE MK 3 ALL MODS

Under constant load the speed and direction of rotation of any two-phase squirrel-cage induction motor are controlled by the magnitude and polarity of the signal impressed on one of the field windings. The Dummy Director Mk 3 all Mods used these characteristics of an induction motor (*M*–2) to generate SHM.

As the rotor of synchro 1*G* turns, the peak value of its 60-cycle output (between taps *S*–1 and *S*–3) changes sinusoidally. The polarity of the a-c output, with respect to the reference voltage, reverses with each one-half revolution of the 1*G*.

This a-c voltage, whose peak value is changing sinusoidally, is impressed on the variable field winding *Fv*. As a result the speed of *M*–2 varies sinusoidally from zero to maximum and back to zero during the first one-half revolution of the 1*G*. During the next one-half revolution of the 1*G* the polarity of its output reverses. Consequently *M*–2 reverses and its speed varies sinusoidally in the opposite direction. Every sinusoidal motion has a reference or zero line. In the Dummy Director Mk 1 the reference line was selected by a handcrank (fig. 12–2). In the Mk 3, Mods 0 and 1, the reference point is changed by selecting any one of the 6-phase outputs of synchro *A*, through *SW*–4, and *T*–2 (fig. 12–5).

Motor *M*–2 drives in response to the sum of the voltages from the 1*G* and *T*–2. To understand the action of the motor, let's first examine its action when the variac is on zero.

Synchro *A* (through the step-down transformer *T*–2) is connected to *Fv* so as to oppose rotation of the motor from the rest point, as in figure 12–6A. If the motor drifts clockwise, the output of *T*–2 increases in the direction required to turn the motor counterclockwise. Consequently the motor remains at rest when the variac is on zero.

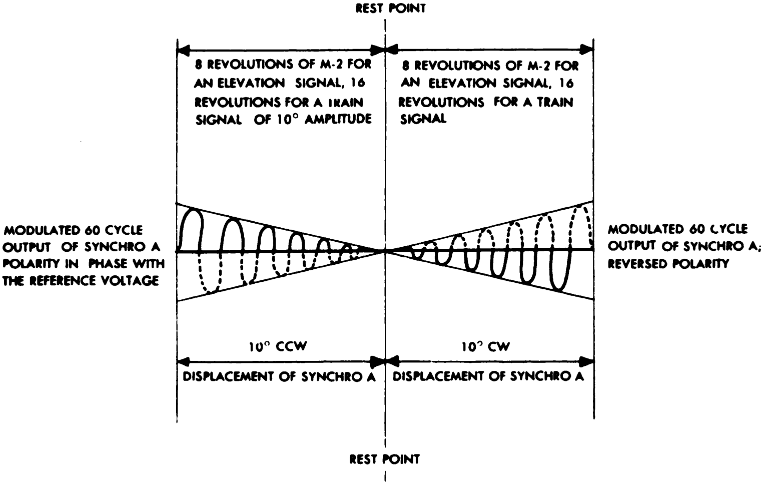

REST POINT
8 REVOLUTIONS OF M-2 FOR AN ELEVATION SIGNAL, 16 REVOLUTIONS FOR A TRAIN SIGNAL OF 10° AMPLITUDE
8 REVOLUTIONS OF M-2 FOR AN ELEVATION SIGNAL, 16 REVOLUTIONS FOR A TRAIN SIGNAL
MODULATED 60 CYCLE OUTPUT OF SYNCHRO A POLARITY IN PHASE WITH THE REFERENCE VOLTAGE
MODULATED 60 CYCLE OUTPUT OF SYNCHRO A; REVERSED POLARITY
10° CCW
10° CW
DISPLACEMENT OF SYNCHRO A
DISPLACEMENT OF SYNCHRO A
REST POINT

**Figure 12–6.—Voltages applied to M–2.**

Since there are six phase outputs of synchro *A*, *M*–2 has six rest points 60° apart around the training circle. You can easily verify this. If you set the variac on zero and turn the reference selector switch, the motor will turn synchro *A* 60° each time.

Let's consider the action of *M*–2 when the variac is set for SHM—say a ten-degree roll. (*M*–2 turns synchro *A* through a gear reduction of 288.1 for an elevation test, and 576.1 when a train signal is desired. Bear in mind also, that the rest point of *M*–2 corresponds to the point of its maximum speed when a sinusoidal signal is impressed on *Fv*.)

The output of the 1*G*, during its first one-half revolution, causes *M*–2 to rotate clockwise. When *M*–2 crosses the rest point it is turning at maximum velocity. (See fig. 12–6A.) Its speed is almost in time phase with the signal voltage from the 1*G*. The output of *T*–2 increases and subtracts from the 1*G* signal.

This opposing voltage (whose peak is approximately equal to the peak output of the variac) acts to decelerate *M*–2, since it is in phase opposition to the 1*G* signal.

When *M*–2 has turned the full amount *CW*, synchro *A* is offset from zero by 10° (for a 10° roll) and is producing its maximum opposing signal:

$$\frac{T\text{–}2 \text{ (primary)}}{T\text{–}2 \text{ (secondary)}} \times (\text{Max. phase output of } A) \times \cos 10^\circ.$$

Then the signal from the 1*G* reverses polarity. But the motor, because of the inertia of the system, overrides the point of reversal. Now the *T*–2 signal is in phase with the 1*G* signal, and the two voltages add to provide the high torque needed to reverse *M*–2. Moreover *T*–2 and 1*G* remain in phase until the motor again crosses the rest point, thus helping to accelerate the motor.

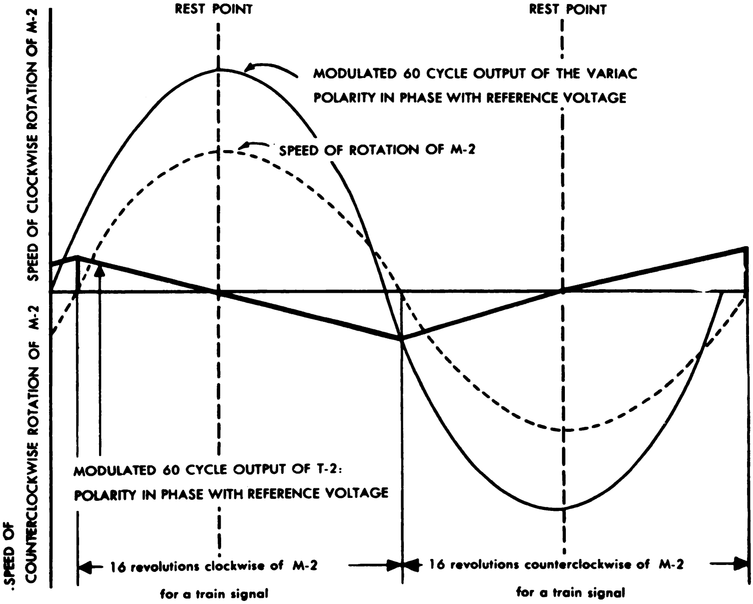


**Figure 12–6A.—Voltages applied to M–2.**

The addition of these two voltages results in the wave shape of figure 12–6B. When the motor is accelerating, the signal voltage is slightly higher than that of a pure sine wave—the reverse is true when the motor is decelerating.

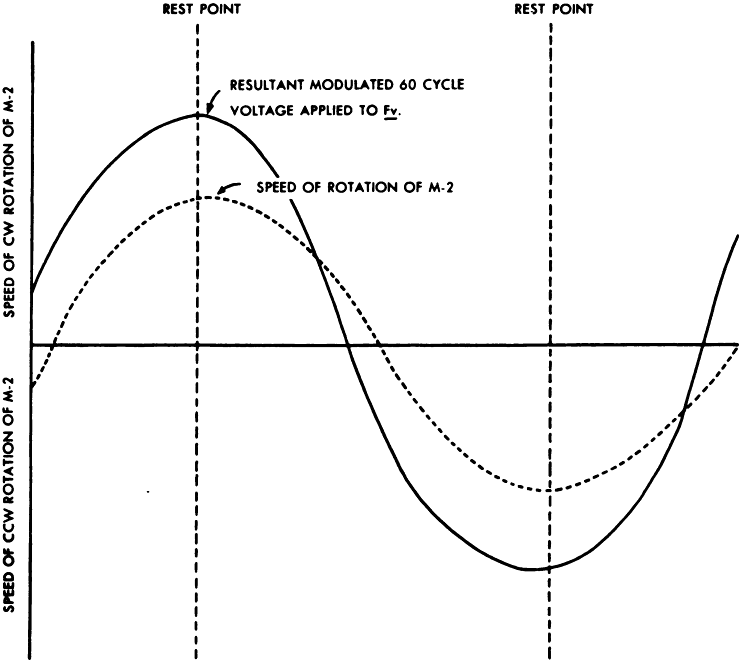


**Figure 12–6B.—Voltages applied to M–2.**

Referring again to figure 12–5, notice that *SW*–3 has two positions—one for train, and one for elevation. When *SW*–3 is on *EL*, *T*–2 steps down the voltage output of synchro *A* by 18 : 1. The step-down ratio is only 9 : 1, however, for a train signal.

This arrangement is logical. The gearing between *M*–2 and synchro *A* is 288 : 1 for an elevation test, and 576 : 1 for a train test. Thus, for a train test (of the same period and amplitude as an elevation test), *M*–2 must turn twice as many revolutions in the same time to produce the same displacement of synchro *A*. Therefore the opposing signal from *T*–2 is halved.

## THE DUMMY DIRECTOR MK 3 MOD 2

Figure 12–7 is a schematic wiring diagram of the Dummy Director Mk 3 Mod 2. The only difference between the Mod 2 and the Mods 0 and 1 is that selector *SW*–4 has been replaced by a synchro differential transmitter (type 1*DG*).

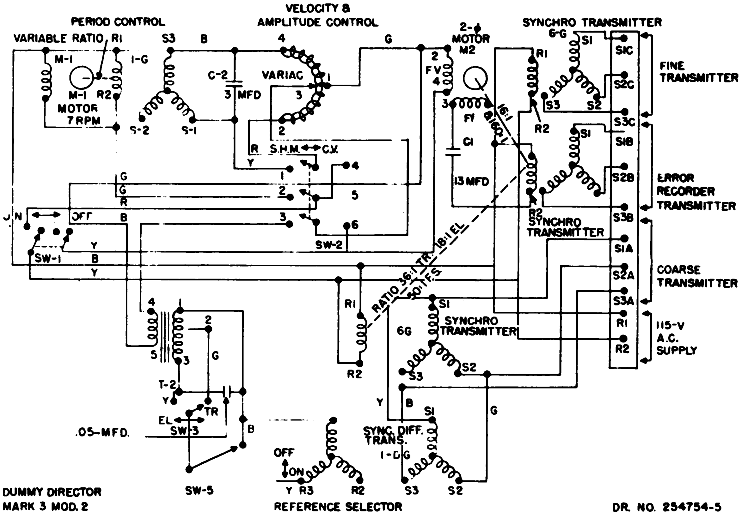


Figure 12–7.—Schematic wiring diagram Dummy Director Mk 3 Mod 2.

The 1*DG* is a distinct improvement over the reference selector switch. The reference line of the SHM can be trained (in an infinite number of steps) through 360°, instead of through only the six steps—each 60° apart—available in the Mods 0 and 1.

The dial group of the Dummy Director Mk 3 Mod 2 is shown in figure 12–8.

## ERROR RECORDER MK 1 MOD 3

The Error Recorder Mk 1 Mod 3, shown removed from its case in figure 12–9, can be used with either the Dummy Director Mk 1 or Mk 3. It records the dynamic error of a

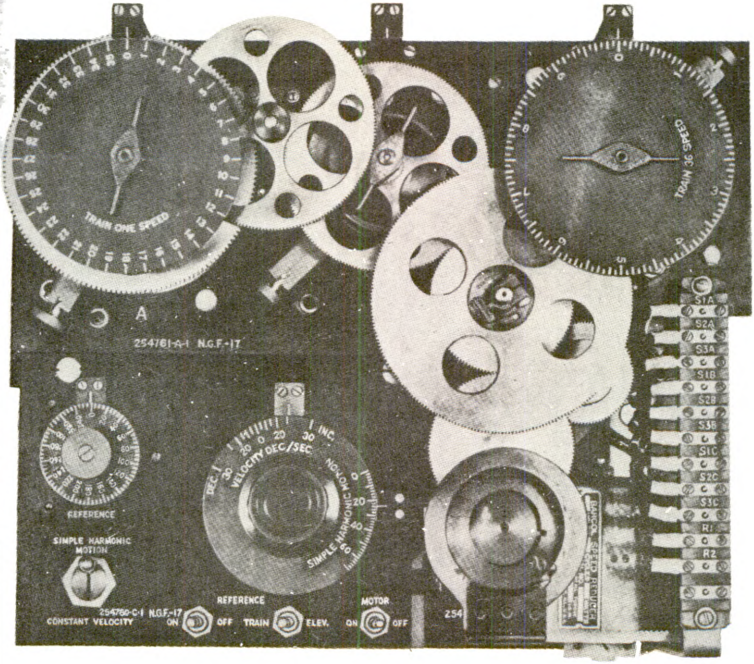
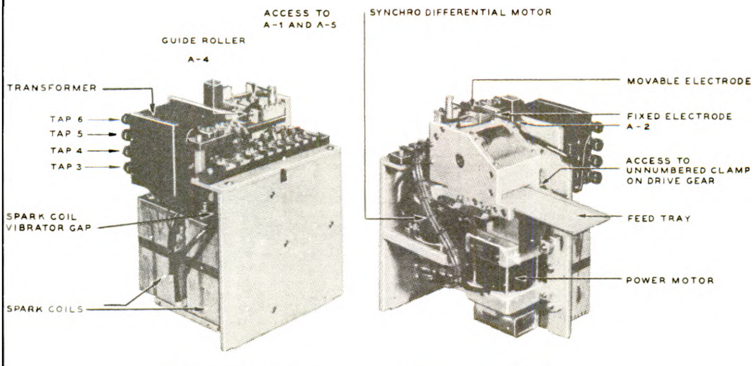


Figure 12–8.—The dial group of the Dummy Director Mk 3 Mod 2.



RIGHT SIDE AND REAR　LEFT SIDE AND FRONT

Figure 12–9.—Error recorder Mk 1 Mod 3 removed from case.

mount when following the automatic signal generated by the dummy director.

The error recorder consists of a paper drive and a recording mechanism. The paper drive is a metallic drum turned at 2 r.p.m. by a synchronous receiver through a speed reducer. The paper is held against the drum by two springs and two rollers, and is driven past the recorder at a constant speed proportional to time.

The recorder consists of an electrode mounted on the shaft of a synchro differential transmitter (type 5*DG*). The electrode is energized by a spark coil (fig. 12–10), and the metallic drum is grounded. When a voltage is impressed on the spark coil, sparks pass between the electrode and the metallic drum, puncturing the paper. Simultaneously a second stationary electrode and spark coil make a straight line at the edge of the paper.

The rotor of the 5*DG*, turning in response to the difference between the electrical signals impressed on its rotor and stator, causes the electrode to swing in an arc across the

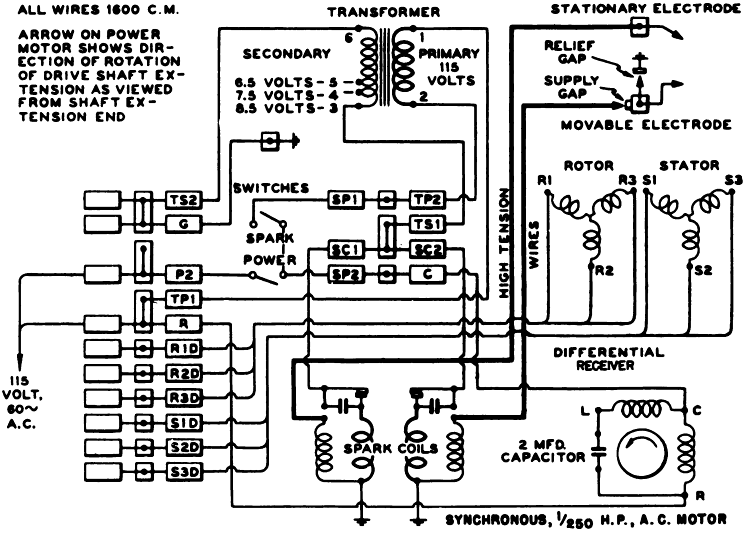
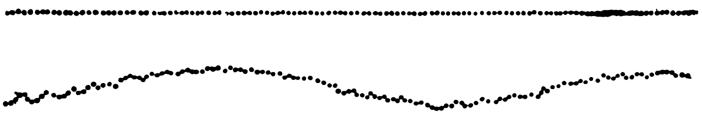


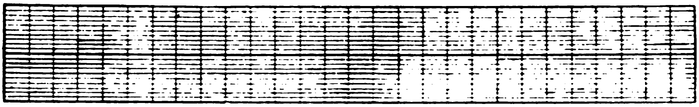
Figure 12–10.—Error recorder Mk 1 Mod 3 wiring diagram.

paper. At the same time, the sparks from the electrode form a permanent record of the displacement of the rotor.

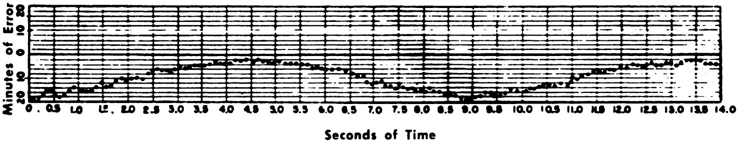
The error between mount position and the signal to the mount, when the mount is following a SHM signal, is in the form of a sine wave. Figure 12–11 is a sample error curve from a Mk 37 Director with Arma controls. The error in response is measured as explained in the figure.



CURVE OBTAINED FOR 25-DEGREE ROLL FOR 9-SECOND PERIOD
(This curve represents an error of 9 minutes of arc)



TRANSPARENT SCALE FOR COMPARISON OF CURVE



COMPARISON OF CURVE WITH TRANSPARENT SCALE

The time from peak to peak is read on the horizontal scale. The error in minutes of arc is read on the vertical scale, and is then divided by 2. Here the reading of 18 ÷ 2 represents an error of 9 minutes, which is within the maximum allowance error of 10 minutes for a roll of 25 degrees. A similar curve, if obtained for a roll of 20 degrees or less, however, would indicate excessive error.

**Figure 12–11.—A sample error curve obtained with a dummy director when checking operation of an Arma-control director in train.**

When the error recorder is used on a mount where the synchro transmission system has a value of 10° for each revolution of the fine synchro, the curve can be read in seconds of time and minutes of error as shown. If any other speed of transmission is used, however, the transparent scales must be recalibrated.

## THE GUNNER'S QUADRANT

The gunner's quadrant is an angle-measuring instrument used to obtain the roller-path data needed to aline the guns in elevation. Both vernier- and drum-type quadrants are in use at present. They differ primarily in the method of reading the scales.

The Mk 3 Mod 1 (fig. 12–12) consists of a level and clamp arm, pivoted about the center of an arc of 100°, that is mounted on a solid steel bar 15″ long, 2″ wide, and ⅝″ thick. The lower surface of the bar is ground-polished to an accurate plane surface.

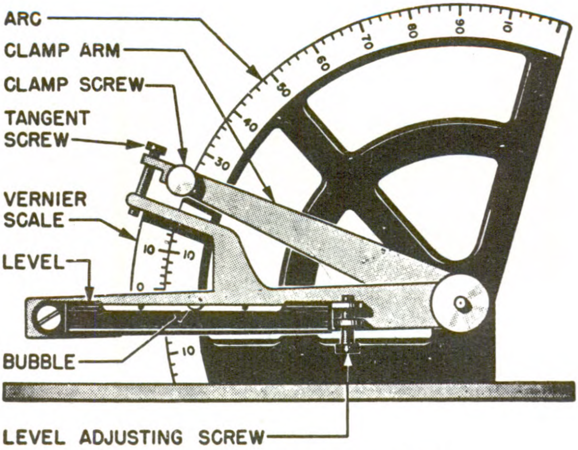


Figure 12–12.—Gunner's quadrant.

The level and clamp arms are pivoted to the arc. The clamp arm serves to secure the level at any particular position on the arc by means of the clamp screw. The clamp arm is connected to the level arm by means of a tangent screw by which fine adjustments may be made between the clamp and the level. The level arm carries the "level"—a glass tube filled with alcohol and containing an air bubble. The upper surface of the glass tube is graduated so that the bubble can be accurately centered. The level arm also carries the vernier scale, which slides along the arc, and a reading glass.

The arc is graduated in degrees (the long graduations), and sixths of a degree (the short graduations).

The vernier scale is graduated in minutes and sixths of a minute, or 10 seconds.

To use the gunner's quadrant, place it carefully on a flat surface parallel to the axis of the gun bore or other object to be measured. Bring the level bubble approximately to the center of the bubble tube by adjusting the clamp and level arms by hand, and tighten the clamp screw, to hold the arms in position. Then turn the tangent screw slowly in the proper direction to bring the bubble exactly in the center of the tube. The measured angle is then read from the arc and vernier scales.

In reading the scale, count along graduations on the arc scale until you come to the zero on the vernier. This will give you a ROUGH reading in degrees and minutes. To get the fine reading, count from the zero on the vernier scale until you come to the division on the vernier scale that lines up exactly with a division on the arc scale. This will give you the FINE reading. Add the coarse and fine reading together to get the total angle of inclination.

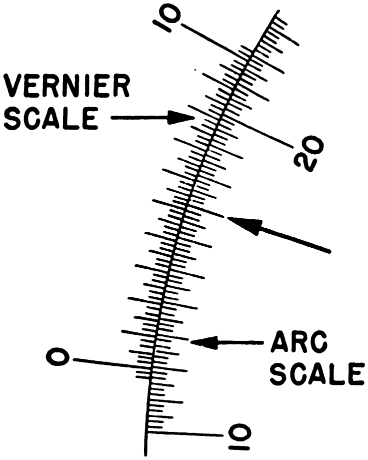


Figure 12–13.—Scales of the gunner's quadrant.

For practice, read the scale shown in figure 12–13. Count along the arc scale until you come to the zero graduation on the vernier scale. This gives you a rough reading of 11°50′.

Now, for the fine reading. Look along the vernier scale until you find a mark that lines up exactly with a mark on the arc scale. Count the number of minutes and seconds between the zero on the vernier scale and this mark. The arrow in figure 12–13 shows this mark. The reading on the vernier scale is 5′10″. Add this to the coarse reading, 11°50′, and you have a total reading of 11°50′10″.

When you are taking a series of readings where the differences are very small, take your readings from the graduated tube without centering the bubble each time. As mentioned before, each graduation to the right or left of the center marks represents five seconds of inclination. So, if the bubble has been centered in the beginning, small angles can be read simply by counting the number of graduations the bubble has moved from the level or central position and multiplying by 5 seconds.

Referring again to figure 12–12, notice that the length of the bubble exactly corresponds to the distance between the two graduations subtended by the small black dots. This is the correct length for the bubble. As the temperature changes, however, the air in the bubble expands and contracts with the contraction and expansion of the liquid. Thus the length of the bubble decreases as the temperature increases.

Provision is made to adjust the length of the bubble by adding or subtracting air. A portion of the glass vial is partitioned off by a glass disk with a small orifice milled in its bottom edge. Extra air is contained in this compartment. If the bubble is too short, stand the quadrant on its base with the pivot down, and bleed more air into the main chamber. If the bubble is too large, reverse the procedure.

## THE GUNNER'S QUADRANT MK 7 (DRUM TYPE)

The Gunner's Quadrant Mk 7 (fig. 12–14) has been designed for easy reading. The vernier scale has been replaced by a micrometer drum mounted on the shaft of the tangent screw. For coarse adjustments, the level arm can be moved to any desired position by disengaging the tangent screw from teeth cut on the arc.

Care must always be exercised in re-engaging the tangent screw after moving the level index arm on the arc. The spring that holds the tangent screw against the arc is strong, and the teeth can be damaged if the tangent screw is allowed to snap into a mesh.

The main scale is graduated as shown in figure 12–14. One revolution of the drum displaces the level arm by 1°. The finest graduation on the drum is 30″ and each 5′ graduation is numbered. The graduations on the glass vial of the spirit level also represent 30″ of arc.

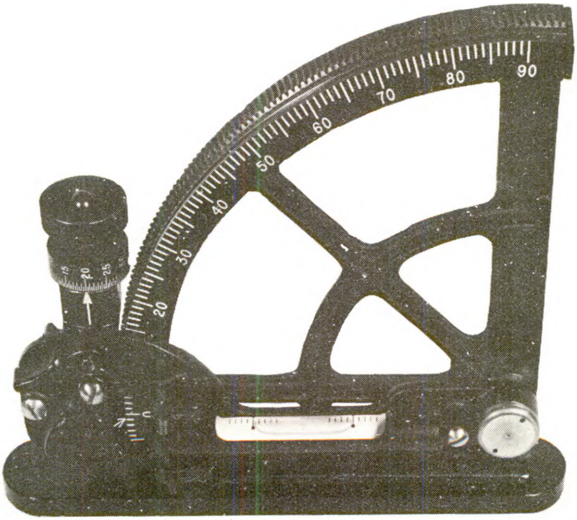


**Figure 12–14.—The gunner's quadrant Mk 7 (drum type).**

While the quadrant is much easier to read, it has one serious disadvantage. Lost motion often exists between the worm and the worm-wheel assembly that drives the level arm. Since the fine reading is read from the drum, any lost motion

## GUNNERS QUADRANT CORRECTION SCALE

MARK 7 NO. 11 DATE 3-4-48

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 23 | + 20" | 46 | + 1' | 69 | - 10" |
| 1 | 0 | 24 | 0 | 47 | + 30" | 70 | 0 |
| 2 | - 20" | 25 | 0 | 48 | + 20" | 71 | - 30" |
| 3 | 0 | 26 | 0 | 49 | 0 | 72 | - 30" |
| 4 | 0 | 27 | + 20" | 50 | 0 | 73 | - 20" |
| 5 | + 20" | 28 | + 20" | 51 | + 20" | 74 | - 20" |
| 6 | - 20" | 29 | + 10" | 52 | + 20" | 75 | - 1' |
| 7 | 0 | 30 | - 1' | 53 | 0 | 76 | - 20" |
| 8 | 0 | 31 | - 30" | 54 | + 20" | 77 | 0 |
| 9 | 0 | 32 | 0 | 55 | + 30" | 78 | 0 |
| 10 | + 20" | 33 | - 30" | 56 | 0 | 79 | - 30" |
| 11 | + 10" | 34 | 0 | 57 | 0 | 80 | - 20" |
| 12 | 0 | 35 | 0 | 58 | 0 | 81 | - 20" |
| 13 | + 10" | 36 | 0 | 59 | 0 | 82 | - 50" |
| 14 | + 20" | 37 | 0 | 60 | 0 | 83 | - 30" |
| 15 | + 30" | 38 | - 1' 30" | 61 | 0 | 84 | 0 |
| 16 | +1' 10" | 39 | - 1' 10" | 62 | - 40" | 85 | - 30" |
| 17 | 0 | 40 | - 20" | 63 | - 10" | 86 | - 40" |
| 18 | + 10" | 41 | 0 | 64 | - 40" | 87 | - 20" |
| 19 | + 30" | 42 | 0 | 65 | 0 | 88 | 0 |
| 20 | + 1' | 43 | + 40" | 66 | + 10" | 89 | - 20" |
| 21 | + 1' | 44 | + 40" | 67 | + 40" | 90 | 0 |
| 22 | + 30" | 45 | + 20" | 68 | - 20" | | |

**Figure 12–15.—Correction sheet for a gunner's quadrant Mk 7.**

of the tangent screw introduces an error—often as much as 20 minutes. However, the lost motion can be eliminated if the tangent screw is always turned in the same direction when centering the bubble.

A second error results from inaccuracies in the teeth cut on the arc. For this reason, all drum-type quadrants are calibrated and a correction scale is issued with each quadrant. The correction sheet for gunner's quadrant Mk 7 (serial no. 11) is shown in figure 12–15. Whenever the quadrant is read, the corresponding correction factor should be applied.

## ADJUSTMENT OF THE GUNNER'S QUADRANT

Both the vernier and drum-type quadrants must be adjusted to read zero when level before taking roller-path data. This is done as follows:

1. Adjust the bubble to the correct length.
2. Select a smooth plane surface that is nearly level. Place the quadrant on this surface, and draw a line around the base of the quadrant. Center the bubble and read the quadrant.
3. Turn the quadrant around so that the inclination is measured in the opposite direction. Be sure that the base of the quadrant lies within the penciled outline. Center the bubble and read the quadrant again.
4. The algebraic sum of these two readings should be zero. If it is not, the quadrant must be adjusted (by the adjustment screw on the level tube) until additional tests show a zero average.

## RADIO RECEIVER ANALYZING EQUIPMENT OE–12

One of the most useful multimeter combinations for circuit analysis is the Radio Receiver Analyzing Equipment Model OE–12, which consists of the components shown in figure 12–16.

The panel and wiring diagram of the D–C Volt/Milliamphere/—Ohmmeter, navy type CV–22193, are shown in figure 12–17. This meter is rated with an accuracy of 2.5

percent for the following ranges: d-c voltage, 0 to 1,000 volts; d-c current, 0 to 100 milliamperes; resistance, 0 to 10 megohms.

Fundamentally, the d-c meter is a d-c microammeter—reading full scale on 50 microamperes—in combination with a series of multiplying- and shunt-resistance networks. By means of the small pin-jacks, the proper multipliers or shunts are selected for the various ranges of voltage or current meas-

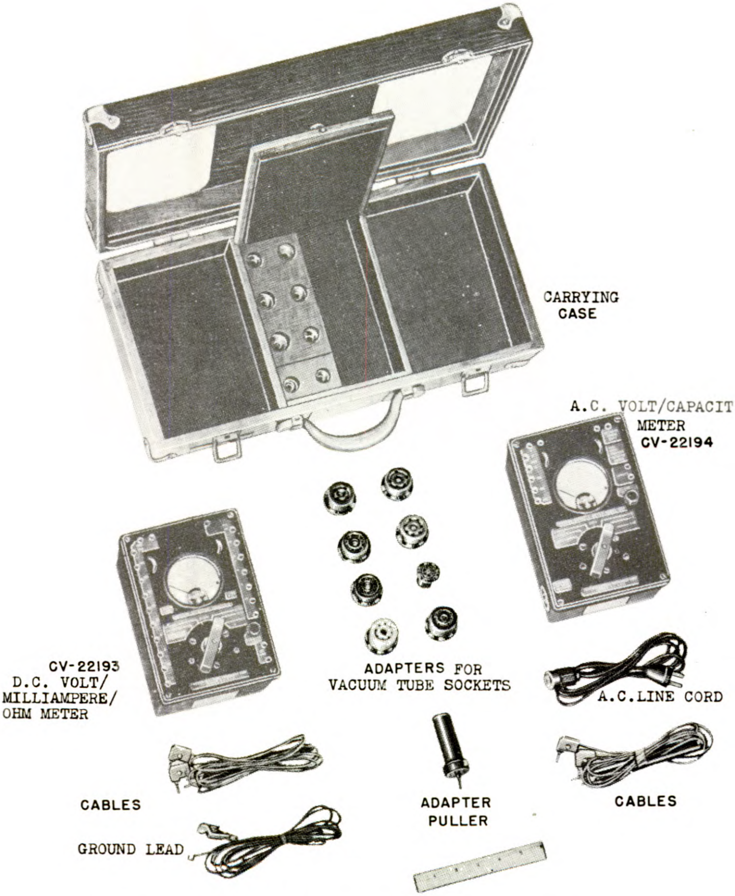
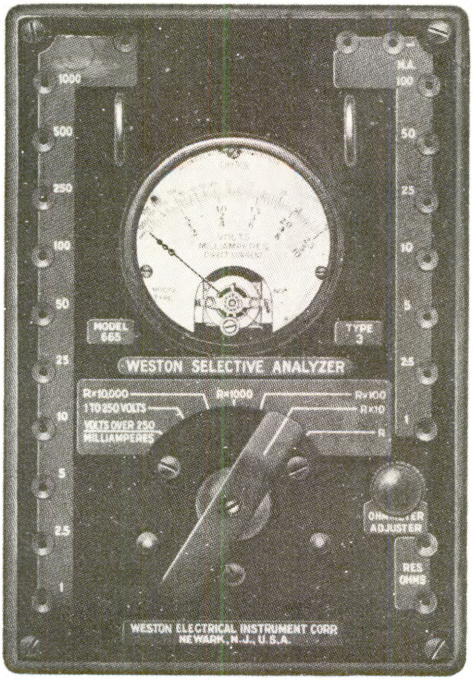
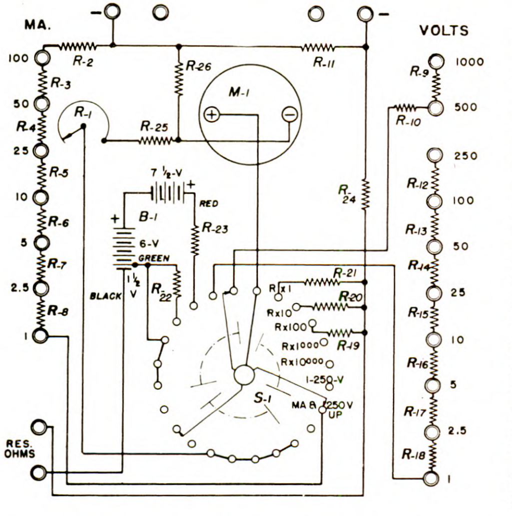

CARRYING CASE
A.C. VOLT/CAPACIT METER CV-22194
CV-22193 D.C. VOLT/ MILLIAMPERE/ OHM METER
ADAPTERS FOR VACUUM TUBE SOCKETS
A.C.LINE CORD
CABLES
ADAPTER PULLER
CABLES
GROUND LEAD

**Figure 12–16.—Model OE–12 analyzing equipment.**





| | |
|---|---|
| B-1 | 75 VOLT BATTERIES |
| M-1 | 50 MICROAMPERE METER |
| S-1 | 7 POSITION SWITCH |
| R-1 | 15,000 OHM RHEOSTAT |
| R-2 | 5.262 OHMS |
| R-3 | 5.262 OHMS |
| R-4 | 10.525 OHMS |
| R-5 | 31.525 OHMS |
| R-6 | 52.625 OHMS |
| R-7 | 105.250 OHMS |
| R-8 | 315.500 OHMS |
| R-9 | 500,000 OHMS |
| R-10 | 489,500 OHMS |
| R-11 | 10,000 OHMS |
| R-12 | 3 MEGOHMS |
| R-13 | 1 MEGOHM |
| R-14 | 500,000 OHMS |
| R-15 | 300,000 OHMS |
| R-16 | 100,000 OHMS |
| R-17 | 50,000 OHMS |
| R-18 | 30,000 OHMS |
| R-19 | 2,800 OHMS |
| R-20 | 252 OHMS |
| R-21 | 24.5 OHMS |
| R-22 | 2,000 OHMS |
| R-23 | 227,000 OHMS |
| R-24 | 3,500 OHMS |
| R-25 | 5,000 OHMS |
| R-26 | 7,500 OHMS |

**Figure 12–17.—Panel view and wiring diagram of the d-c volt/milliampere ohmmeter.**

urement. The resistance ranges are selected by the rotary switch. The switch has two additional positions: one for the 1- to 250-volt range; and one for the 500- to 1,000-volt ranges and for all milliampere ranges.

An internal power supply of 15 volts d. c.—two 7.5-volt dry cells—is provided for reading resistance values. The small rheostat on the front panel, marked "ohmmeter adjuster," is used to compensate for variations of battery voltage when measuring resistance.

As a voltmeter the sensitivity is 20,000 ohms per volt up to and including the 250-volt range; and 1,000 ohms per volt on the 500- and 1,000-volt ranges. Therefore, the full scale current consumption is 50 microamperes up to and including the 250-volt range, and 1 milliampere on the 500- and 1,000-volt ranges.

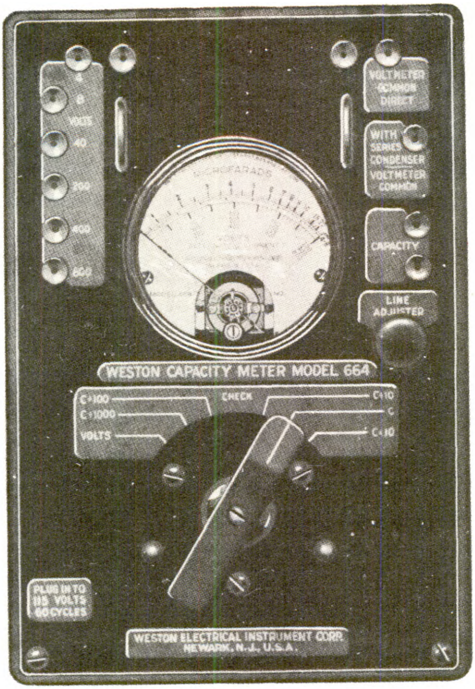
The current and voltage ranges have been designed so that the ratio between any two adjacent ranges is never above 2.5. For most ranges, the ratio is 2. Accordingly, readings can usually be taken above the half-scale mark thus greatly improving the accuracy of all current and voltage readings.

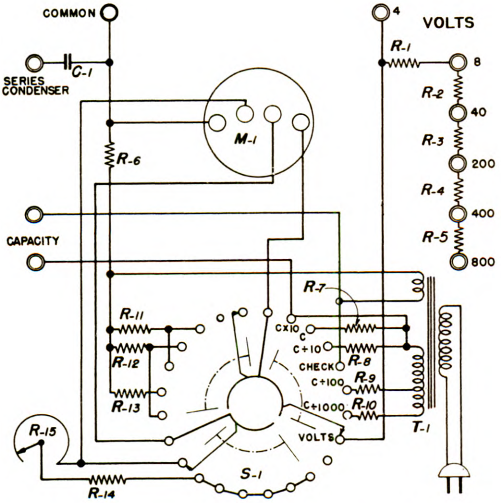
## THE AC VOLT/CAPACITY METER, NAVY TYPE CV–22194

The meter shown in figure 12–18 is a multi-purpose a-c meter suitable for the measurement of voltage and capacity. The readings are made on an a-c copper-oxide rectifier-type microammeter that reads full scale on 230 microamperes. This microammeter, in combination with the proper multipliers and accurately adjustable source of a-c potential, is used for reading either a-c voltage or capacity.

When used as a voltmeter, the 230-microampere meter is shunted so as to read full scale on 1 milliampere and has a sensitivity of 1,000 ohms per volt for all ranges. The rotary switch is placed in the "volts" position, and the external connections are made by plugging the test leads into small pin jacks on the face of the panel. Markings adjacent to the pin jacks indicate the various voltage ranges.

An extra jack marked "with series condenser—voltmeter


4
8
VOLTS
40
200
400
800
VOLTMETER COMMON DIRECT
WITH SERIES CONDENSER VOLTMETER COMMON
CAPACITY
LINE ADJUSTER
MICROFARADS
WESTON CAPACITY METER MODEL 664
C÷100
C÷1000
VOLTS
CHECK
C÷10
C
C×10
PLUG INTO 115 VOLTS 60 CYCLES
WESTON ELECTRICAL INSTRUMENT CORP. NEWARK, N.J., U.S.A.



| | |
|---|---|
| C-1 | .25 MFD. |
| M-1 | 230 μA. METER |
| S-1 | 7 POSITION SWITCH |
| T-1 | TRANSFORMER |
| R-1 | 4,000 OHMS |
| R-2 | 32,000 OHMS |
| R-3 | 160,000 OHMS |
| R-4 | 200,000 OHMS |
| R-5 | 400,000 OHMS |
| R-6 | 11,400 OHMS |
| R-7 | 11 OHMS |
| R-8 | 130 OHMS |
| R-9 | 36,500 OHMS |
| R-10 | 375,000 OHMS |
| R-11 | 5,200 OHMS |
| R-12 | 39.1 OHMS |
| R-13 | 405 OHMS |
| R-14 | 800 OHMS |
| R-15 | 4,000 OHM RHEOSTAT |

**Figure 12–18.—Panel view and wiring diagram of a-c volt/capacity meter.**

common" is provided to block any d. c. present in the a-c voltage being measured.

When taking capacitance readings turn the rotary switch to the "check" position and adjust the pointer to the full scale or "infinite capacity" position. After adjusting the meter turn the switch to the proper capacity range. Condensers having capacitances of from 0.0001 to 200 mfd. can be measured. A small rheostat on the front of the panel compensates for variations in a–c line voltage when reading capacitances.

## ADAPTER SET

A group of tube-socket adapters are included in the Model OE–12 equipment (fig. 12–16). The set includes a color-coded adapter for each of the eight standard vacuum tube bases. Each individual pin in the adapters is not only connected to the equivalent tube socket connection, but has a tab projecting radially through the side of the adapter as well. Small holes are drilled in the tabs to hold the point of a test prod while taking potential or resistance readings.

These adapters are helpful when socket connections on the underside of the chassis are inaccessible. To take a reading from the top of the chassis, remove the tube from the circuit under test, select the adapter with the correct pin arrangement, plug it into the chassis tube socket, and replace the tube in the top of the adapter. Proceed with the necessary readings. Always consult a standard tube base list for the pin numbers of the electrodes. You will find these numbers engraved in the bakelite beside each tab of the adapter.

## CARE OF INSTRUMENTS

Whenever you use a piece of test equipment, always remember that it is a sensitive instrument. Precautions must always be taken to avoid injuring meter pivots, bending the pointers, or burning out the moving elements or circuits. The following safety precautions must always be observed.

1. Don't drop the instruments, or otherwise jolt them severely.

2. When measuring current or voltage, always start with the highest range and work down, regardless of what value of current you expect.
3. When measuring resistance or capacitance, always disconnect the equipment under test from all power and discharge all capacitances.
4. Never connect test leads for two measuring functions, such as current and voltage, from a meter to a piece of equipment under test. Remove all test leads with the exception of the two required for the measurements being made.
5. For voltage and current measurements use the range that will produce the fullest scale readings.
6. For resistance and capacitance measurements use the range that will come closest to mid-scale readings.
7. If the pointer has a tendency to stick, tap the instrument glass lightly with your fingernail or a pencil eraser before reading the meter.
8. Always study carefully the manufacturer's or NavShips instructions for a particular meter before attempting to use the instrument.

## VACUUM TUBE ANALYZERS

The vacuum tube analyzers (testers) are all designed to provide an accurate portable means—consistent with the size and weight—of checking a variety of vacuum tubes for the following characteristics: transconductance, cathode emission, shorts, gas and noise.

## THE TRANSCONDUCTANCE TEST

Of the many measurable characteristics of a vacuum tube, the transconductance test is the one most closely associated with operation performance. You should remember that transconductance, expressed in microohms, is the amount of charge in plate current *Ip* produced by a one-volt change in grid voltage *Eg* with the plate voltage *Ep* held constant.

The transconductance test is the one that generally determines the end of the useful life of all but rectifier, diode, and cold cathode-type tubes.

## THE SHORT TEST

The short test of a vacuum tube consists of a series of checks for shorts or leaks between the elements. The tube is switched into various circuit combinations and a short or leakage will result in the lighting of a neon lamp. Intermittent shorts can be detected by tapping the tube with your finger while turning the switch. An instantaneous flash of the lamp as the switch is turned is to be disregarded. It is caused by the capacity within the circuit. The tube data sheet should always be consulted before discarding a tube, because many tubes of recent design have cross connections and taps that will cause the neon lamp to glow on certain positions of the test switch even though the tube is in satisfactory operating condition.

## THE GAS TEST

A high-vacuum tube is checked for excessive gas by increasing the resistance of the grid circuit and noting if there is any appreciable change in plate current. Ordinarily no grid current flows in a high-vacuum tube; thus both the bias and the plate current of the tube should be unaffected by an increase in the resistance of the grid circuit. If gas is present in the tube, however, current will flow in the grid circuit and the grid bias will be changed by the amount of the voltage drop in the resistor. Thus a marked change in the plate current—when the resistance of the grid is changed—will indicate excessive gas in the tube.

## THE NOISE TEST

Provision is often made to connect a radio telephone receiver in to the circuit of a tube under test. If the tube has any loose elements they will vibrate and cause static when the tube is tapped lightly. This static noise can always be distinguished from the 60-cycle hum of the tube tester's power supply. The noise test can also be used to detect intermittent contacts too brief for the neon lamp test.

## RECTIFIER TUBE OR CATHODE EMISSION TESTS

Some analyzers include a circuit for testing the cathode emission of rectifiers, diodes, and cold cathode tubes such as the *OZ4*. An a–c voltage of definite value is applied across the tube under test and the resultant rectified current is indicated on the meter. The two sections of a full wave rectifier are tested separately. Cold cathode rectifiers require a higher a–c voltage than heater or filament-type rectifiers. Diodes require a lower a-c voltage than regular rectifier tubes and a protective series resistance must be added as well.

## MULTIMETER SECTION

Some tube analyzer sets include a multimeter for circuit analysis work. The multimeter can be used for the measurement of a-c and d-c voltages, direct current, and resistance. The ranges of the instrument are usually: current, 0 to 20 and 0 to 200 milliamperes; resistance, 0 to 2,000, 0 to 20,000, and 0 to 2,000,000 ohms; capacity, to a maximum of at least 20 microfarads.

## PRECAUTIONS IN THE USE OF VACUUM TUBE ANALYZERS

The following general precautions apply to the operation of most vacuum tube analyzers:

1. Don't insert a tube until you are sure that the filament voltage is set at the correct value for that tube. Refer to a tube data sheet.
2. Never attempt to test a tube until it has been found clear in the short test.
3. Don't change the position of the filament volts switch when a tube is in one of the sockets.
4. Always bring the GRID VOLTAGE UP FIRST since a high plate voltage without any grid voltage may draw abnormally high currents—high enough to damage the tube tester.

5. Never test rectifiers beyond their maximum current-carrying capacity.
6. Never make a total emission test at a current greater than the value specified for the tube. Always make emission test quickly to minimize damage to the tube—abnormal currents will frequently remove all the coating from the filament or cathode.
7. Always shut the tube tester off when you have finished and return all accessories to their proper places.

## METHODS OF SERVICING AND TESTING ELECTRONIC EQUIPMENT

Whenever a casualty occurs in a piece of electronic equipment, test the vacuum tubes in the faulty section. If the tubes are not at fault, either the dynamic or the static method of servicing may be followed.

The dynamic method requires a calibrated source of variable frequency such as a standard signal generator. A signal of measurable frequency is impressed on the equipment and the sensitivity, selectivity, amplification, etc., of the various stages are measured with the equipment in operating condition. The dynamic method of test is valuable primarily for determining the overall condition of the equipment. The actual casualty can be isolated by the static method.

When the static method of testing the equipment is used, the individual voltages, currents, resistances, and capacitances of the various circuits are measured with electrical measuring instruments. The static method of testing equipment is based on the assumption that if all the component parts of an electronic device are in operating condition and their electrical characteristics intact, the system will function properly as a whole.

Always study the wiring diagrams and test procedures outlined in the instruction books before attempting any repair work on electronic equipment. These manuals list the voltages and currents to be expected at different test points, and the proper sequence of testing the component circuits.

If instruction books are not available, it is often possible to obtain complete data from a similar piece of equipment that is operative. This information should be recorded for future use. The voltage and current readings from a duplicate instrument may not be identical, but they will be close enough for successful use if no other data is available.

If there are no written instructions or similar equipment, reference must be made to the proper operating voltages and current values for the various vacuum tubes as listed in a standard tube manual. These tube characteristics can be used as a basis for tests.

Remember that the equipment was properly designed and was at one time operative; that failure to operate is usually the result of failure of one or more component items such as capacitors, resistors, or wiring; that such items are usually subject to complete failure, rather than a slow change in characteristics such as occurs with vacuum tubes. If you remember these three general assumptions, then you can usually test any piece of electronic equipment, even in the absence of instructions.

## STATIC METHODS OF TESTING ELECTRONIC EQUIPMENT

There are two procedures that may be used in testing and analyzing equipment by the static method. The first is the direct or point to point method, using either the Model OE–12 equipment or similar instruments. Connections are made to the socket terminals or other associated terminals on the underside of the chassis. The second method is the top chassis analysis method. The tube socket adapters are placed in the tube sockets with the tubes in the top of the adapters. Readings are taken between any two of the radial tab contacts.

The point to point method may be used to record the voltages encountered with the equipment energized. Using a common point, usually the chassis or negative high voltage as a reference point, each circuit is considered individually and the voltage tested and recorded at progressive points toward each tube element. A sudden loss of voltage indicates an open circuit, a shorted capacitor, or a burned-out resistor. Such a casualty can be individually isolated by further resistance tests with the equipment inoperative.

In the top chassis analysis method the tubes are pulled one at a time, the correct adapter inserted in the socket, and the tube replaced in the socket section of the adapter. This brings the voltages on the tube elements out to the radial adapter connections, where readings of the potential applied between any two elements can be made.

When taking potential readings with respect to the cathode, the negative or black test lead should be connected to the cathode pin tab. (Refer to a tube chart for the pin connections.) Connect the red or positive lead from the meter to the plate or screen circuits for positive potentials. For grid readings, the polarity of the test leads must be reversed. In some cases, the grid bias may be measured by taking the drop across the cathode resistor to chassis (ground).

If a. c. is used for the tube filament supply, an a-c meter must be used for recording filament potentials. Never attempt to measure a-c voltage or current with a d-c meter. Always measure filament voltage across the filament, because the filament circuits in many circuits are maintained at a high d-c potential with respect to ground. Never attempt to measure filament voltage from one side of the filament to the ground.

## QUIZ

1. A dummy director is used to conduct
    a. static accuracy tests.
    b. dynamic accuracy tests.
    c. synchro transmission tests.
    d. director and gun transmission tests.
2. The dummy director transmits orders to
    a. two synchro circuits.
    b. one synchro circuit.
    c. three synchro circuits.
    d. two synchro circuits and the director or gun.

3. The motor of the (Dummy Director) Mk 1 Mod 3 turns
    a. one input to the component integrator.
    b. both inputs to the component integrator.
    c. the component integrator and the 1*DG*.
    d. the component integrator and the 2-phase motor.
4. In the (Dummy Director) Mk 3 Mods a _______________ furnishes the sinusoidal signal to the variac.
5. In the Mk 3 Mod 2 the reference selector switch is replaced by a _____________.
6. The error recorder receives two signals, one from the __________ and one from the __________.
7. What are the two types of gunner's quadrants?
8. If a gunner's quadrant is to be adjusted to read zero when level, the adjustment should be made by the
    a. tangent screw.
    b. clamp screw.
    c. drum.
    d. adjusting screw.
9. An a–c voltmeter, such as the one issued with the Model OE–12 test equipment has an internal resistance of at least
    a. 10 ohms per volt.
    b. 100 ohms per volt.
    c. 1,000 ohms per volt.
    d. 10,000 ohms per volt.
10. A series condenser is placed in the test lead of the a–c meter to
    a. suppress arcing.
    b. block d. c.
    c. smooth out the a. c.
    d. block the a. c.
11. When testing a capacitor with a capacity meter
    a. leave the circuit energized.
    b. open the circuit and ground the capacitor.
    c. open the circuit and discharge the capacitor.
    d. open the circuit and short the capacitor.
12. The most useful test applied to multielement vacuum tubes is the _____________.
13. Rectifiers, diodes, and cold cathode-type tubes are tested by the
    a. emission test.
    b. gas test.
    c. emission, and short tests.
    d. emission, short, and gas tests.
14. What are the assumptions for static accuracy test?

# CHAPTER 13

## OBSERVATION AND ANALYSIS OF GUNNERY EXERCISES

### OBSERVING PARTY

Most fleet gunnery exercises are fired for the purpose of training the fire control, ship control, and gun crews to fight the ship effectively during combat. Whenever possible, therefore, the gunnery exercises are designed to simulate battle conditions, and results are carefully observed.

The results of the firing are necessary to determine both the effectiveness of the ship as a combat unit and the relative efficiency of the various gun, fire control, and ship control crews. Observers are stationed throughout the firing ship and on the observing vessels to record all information related to the gunnery exercises. When the problem is completed, a postfiring analysis is conducted; from this analysis it is often possible to suggest methods of increasing the effectiveness of the ship as a combat unit.

The postfiring analysis is no more accurate than the information recorded by the observers. For this reason observing parties are carefully selected and trained, and procedures are organized to coordinate their efforts.

The complete organization of the observing party, their duties, the forms used, and the data to be recorded are described in CONFIDENTIAL publications issued for a particular type of gunnery exercises.

A chief observer, who is guided by these CONFIDENTIAL publications, is in charge of the entire observing party. It is his responsibility to indoctrinate the crews and see that the time of firing, fall of shot, range, sight angle, deflection spots, and so on, are recorded. He issues instructions and the necessary forms to the various observers.

You, as a leading petty officer, will likely be placed in charge of an observing party in a plotting room or director, and will be responsible to the chief observer. If the observers under your supervisions, as well as those throughout the ship, accurately record the required data, such data will be invaluable in determining the merit of the practice. The merit of the ship in practice determines its effectiveness in battle.

Be sure that the observers in your party understand their duties, and that the collection of information is kept secondary to the proper operation of the equipment. You should station each man so that he can record his data and still not interfere with the operator and the proper performance of his duties. Quite often this is difficult to do; whenever possible, therefore, a rehearsal run is conducted. During the rehearsal, each team is given the opportunity to adjust its position and thus ensure both the proper operation of the equipment and the accurate recording of firing information.

When a particular phase of a gunnery exercise is completed, all data and recorded information must be turned over to the chief observer or his representative. This information should not be lost or misplaced. It is CONFIDENTIAL and must be treated as such. You should caution all observers against discussing the results of any gunnery exercises with unauthorized persons.

## Selection and Training of Observers

The personnel selected for an observing party should be reliable petty officers. Where practicable, the man assigned to a specific station should have had experience in the operation of similar equipment. If personnel from another ship are assigned as observers, each man should have served at the same battle station on his own ship. If it isn't possible to assign experienced personnel, the men selected should be carefully instructed in the proper method of reading the instruments at their observing stations BEFORE the practice begins. Be sure each man understands the importance of accurate readings.

### Safety Precautions and the Observing Party

The observer at a specific station has a twofold job: he not only collects and records information, but he must be alert to detect any violation of safety precautions as well. Heavy penalties are imposed against a firing ship's merit if the safety precautions or other rules and regulations prescribed for the gunnery exercise are violated.

It is often possible to fire faster or to have greater assurance of completing a firing run within the allotted time if certain precautions are ignored. It is the observer's job to watch for and prevent any violation of safety precautions at his particular station that would endanger the safety of the ship or the crew. If the observer prevents violations or other careless tactics, he will have done the Navy and his ship a service. The methods of loading and firing learned in peacetime are carried over to actual combat. In battle the disregard of safety precautions can be disastrous for the whole ship.

## CAMERA PARTY

Much valuable and accurate information on the results of firing is recorded by cameras, especially at long ranges where a constructive target is used. Photographs are taken of the splashes from the air and from the towing ship. Data taken from these photographs can be accurately plotted and will thus show the accurate position, in relation to the target, of the fall of shot. As a rule, the camera parties are made up as a semi-permanent detail, so that the same personnel compose these parties and thus record the fall of shot for all ships in their specific area. This ensures more accurate data because the photos are taken by an experienced group capable of accurately recording and photographing fall of shot. To ensure accurate information, the camera data are compared with the fall-of-shot data as recorded by the rake observers on the towing or the reference vessel.

## FORMS FOR OBSERVERS

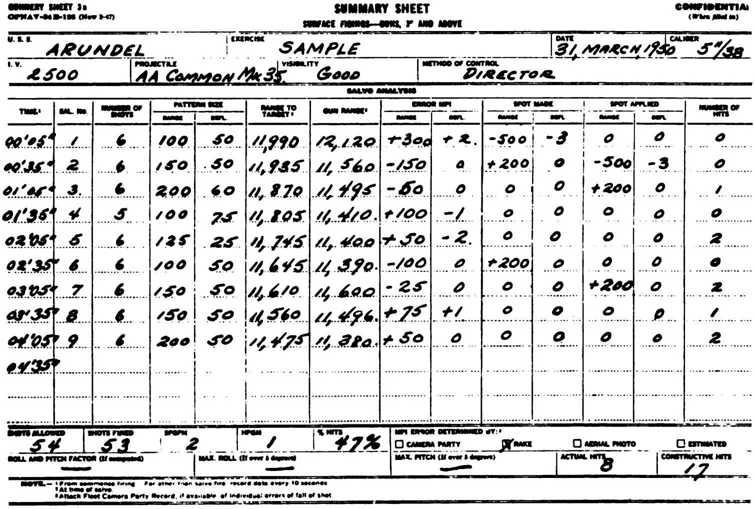
The forms which the individual observers use come in pads. They are issued to the observers by the chief observer, in ample time to be studied thoroughly before the firing run. In the event that printed forms are not available, the desired information may be recorded on plain sheets of paper, as long as the required information is obtained and neatly recorded. After each run, the recorded data are turned in to the chief observer. If another run is scheduled, more forms are issued by the chief observer, and the observers return to their stations.

Upon completion of the practice, the data for each run are evaluated and analyzed by the gunnery officer or one of his qualified assistants. Then the necessary gunnery sheets are filled out preparatory to sending them to the Chief of Naval Operations, Bureau of Ordnance, Type Commanders, or such other activities as may require them. Remember that when filled in these forms are CONFIDENTIAL.

You may be concerned at times as to why so much data is taken by the observing party when apparently so little of it is used in filling out the forms on which the practices are reported. One important reason is that the extra data may be the clue to an explanation of an error, or errors, for which otherwise there would be apparently no explanation. With enough firing data, it is often possible to determine whether errors are caused by personnel or by the equipment, and where.

## USING THE OBSERVERS DATA

In figure 13–1 parts A and B, you are shown the front and back of a typical gunnery sheet designated 3a. This sheet is filled in, in this case, with hypothetical data. It serves to show you, in part, how the information gathered by the observing party is utilized and why it is important that the



GUNNERY SHEET 3a
OPNAV-34B-126 (New 3-47)

SUMMARY SHEET
SURFACE FIRINGS—GUNS, 3" AND ABOVE

CONFIDENTIAL
(When filled in)

| | | | | |
|---|---|---|---|---|
| U. S. S. ARUNDEL | EXERCISE SAMPLE | | DATE 31, MARCH 1950 | CALIBER 5"/38 |
| I. V. 2500 | PROJECTILE AA COMMON Mk 35. | VISIBILITY GOOD | METHOD OF CONTROL DIRECTOR | |

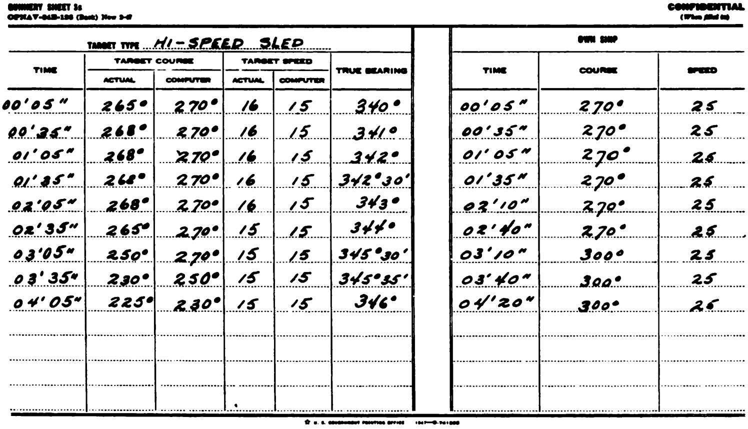
SALVO ANALYSIS

| TIME¹ | SAL. No. | NUMBER OF SHOTS | PATTERN SIZE | | RANGE TO TARGET² | GUN RANGE² | ERROR MPI | | SPOT MADE | | SPOT APPLIED | | NUMBER OF HITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RANGE | DEFL. | | | RANGE | DEFL. | RANGE | DEFL. | RANGE | DEFL. | |
| 00'05" | 1 | 6 | 100 | 50 | 11,990 | 12,120 | +300 | +2. | -500 | -3 | 0 | 0 | 0 |
| 00'35" | 2 | 6 | 150 | .50 | 11,935 | 11,560 | -150 | 0 | +200 | 0 | -500 | -3 | 0 |
| 01'05" | 3. | 6 | 200 | 60 | 11,870 | 11,495 | -50 | 0 | 0 | 0 | +200 | 0 | 1 |
| 01'35" | 4 | 5 | 100 | 75 | 11,805 | 11,410. | +100 | -1 | 0 | 0 | 0 | 0 | 0 |
| 02'05" | 5 | 6 | 125 | 25 | 11,745 | 11,400 | +50 | -2. | 0 | 0 | 0 | 0 | 2 |
| 02'35" | 6 | 6 | 100 | 50 | 11,645 | 11,390. | -100 | 0 | +200 | 0 | 0 | 0 | 0 |
| 03'05" | 7 | 6 | 150 | 50 | 11,610 | 11,600 | -25 | 0 | 0 | 0 | +200 | 0 | 2 |
| 03'35" | 8 | 6 | 150 | 50 | 11,560 | 11,496. | +75 | +1 | 0 | 0 | 0 | 0 | 1 |
| 04'05" | 9 | 6 | 200 | 50 | 11,475 | 11,380. | +50 | 0 | 0 | 0 | 0 | 0 | 2 |
| 04'35" | | | | | | | | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| SHOTS ALLOWED 54 | SHOTS FIRED 53 | SPGPM 2 | HPGM 1 | % HITS 47% | MPI ERROR DETERMINED BY:³ ☐ CAMERA PARTY ☒ RAKE ☐ AERIAL PHOTO ☐ ESTIMATED |
| ROLL AND PITCH FACTOR (If computed) — | MAX. ROLL (If over 5 degrees) — | | MAX. PITCH (If over 5 degrees) — | ACTUAL HITS 8 | CONSTRUCTIVE HITS 17 |

NOTE.—¹From commence firing. For other than salvo fire record data every 10 seconds.
²At time of salvo.
³Attach Fleet Camera Party Record, if available, of individual errors of fall of shot.

Figure 13–1.—(A) Example of Gunnery Sheet 3a (front) filled in for a hypothetical practice.



GUNNERY SHEET 3a
OPNAV-34B-126 (Back) New 3-47

CONFIDENTIAL
(When filled in)

TARGET TYPE HI-SPEED SLED

| TIME | TARGET COURSE | | TARGET SPEED | | TRUE BEARING | OWN SHIP TIME | OWN SHIP COURSE | OWN SHIP SPEED |
|---|---|---|---|---|---|---|---|---|
| | ACTUAL | COMPUTER | ACTUAL | COMPUTER | | | | |
| 00'05" | 265° | 270° | 16 | 15 | 340° | 00'05" | 270° | 25 |
| 00'35" | 268° | 270° | 16 | 15 | 341° | 00'35" | 270° | 25 |
| 01'05" | 268° | 270° | 16 | 15 | 342° | 01'05" | 270° | 25 |
| 01'35" | 268° | 270° | 16 | 15 | 342°30' | 01'35" | 270° | 25 |
| 02'05" | 268° | 270° | 16 | 15 | 343° | 02'10" | 270° | 25 |
| 02'35" | 265° | 270° | 15 | 15 | 344° | 02'40" | 270° | 25 |
| 03'05" | 250° | 270° | 15 | 15 | 345°30' | 03'10" | 300° | 25 |
| 03'35" | 230° | 250° | 15 | 15 | 345°35' | 03'40" | 300° | 25 |
| 04'05" | 225° | 230° | 15 | 15 | 346° | 04'20" | 300° | 25 |

☆ U. S. GOVERNMENT PRINTING OFFICE 1947—O-[illegible]

Figure 13–1.—(B) Example of Gunnery Sheet 3a (back) filled in for a hypothetical practice.

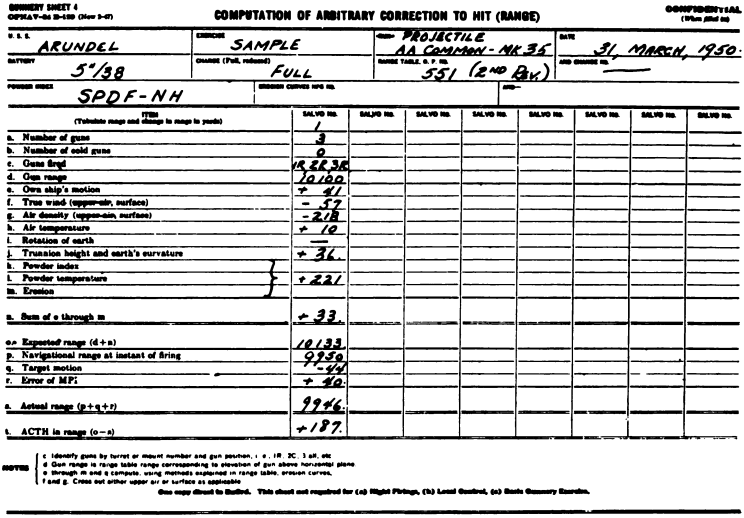
observers record the information accurately. The Gunnery Sheet 3a is self-explanatory. There are several other gunnery sheets, but the one shown will give you a general idea of the type of information they all contain when filled in.

Fire Control Technicians are often called upon to assist in filling out the various gunnery sheets from the observed data. In general very little trouble will be encountered in completing these forms. However, there are exceptions; and one form in particular (Gunnery Sheet 4) has been selected for a complete explanation. One important reason for this selection is that the Fire Control Technician is more apt to work with this form than with the others. Another reason is that, since many of the required computations are made with the help of a range table, further explanation of the items on the sheet is essential.

## COMPUTATION OF GUNNERY SHEET 4

Before going into detail as to how each item on Gunnery Sheet 4 is computed, let us see just what we are going to determine by carrying out these computations and let us also see very briefly how the job is done.

Referring to figure 13–2, parts A and B, you can see that the problem is broken down into two parts. The range problem is on the front (fig. 13–2, part A), and the deflection problem is on the back (fig. 13–2, part B) of Gunnery Sheet 4. The final result of the entries on the front of the sheet will be the ARBITRARY CORRECTION TO HIT (ACTH) in range. The result of the entries on the back of the sheet will be the ACTH in deflection. This information over a period of time can be very useful. It is obvious that to estimate the cold-gun correction from the information on these sheets would not be hard. The more sheets of previous firing available, the more accurate the cold-gun correction estimate will be. In addition to its primary purpose of furnishing information to the Bureau of Ordnance, to the Chief of Naval Operations, and to the Type Commanders, this is another of the many uses of the sheet.



GUNNERY SHEET 4
OPNAV-34 B-120 (Nov 3-47)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

CONFIDENTIAL
(When filled in)

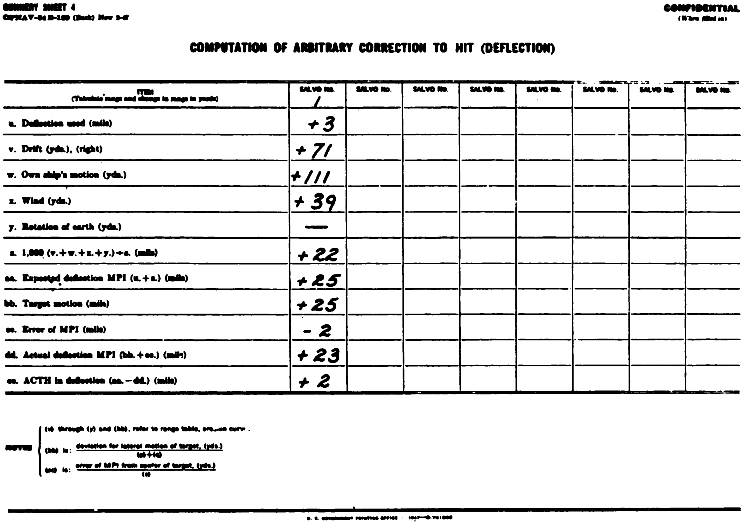
U. S. S. ARUNDEL
EXERCISE SAMPLE
PROJECTILE AA COMMON - MK 35
DATE 31, MARCH, 1950.
BATTERY 5"/38
CHARGE (Full, reduced) FULL
RANGE TABLE, O. P. NO. 551 (2ND Rev.)
AND CHANGE NO. —
POWDER INDEX SPDF-NH
EROSION CURVES NPG NO.
AND—

| ITEM (Tabulate range and change in range in yards) | SALVO No. 1 | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. |
|---|---|---|---|---|---|---|---|---|
| a. Number of guns | 3 | | | | | | | |
| b. Number of cold guns | 0 | | | | | | | |
| c. Guns fired | 1R 2R 3R | | | | | | | |
| d. Gun range | 10100 | | | | | | | |
| e. Own ship's motion | + 41 | | | | | | | |
| f. True wind (~~upper-air~~, surface) | - 57 | | | | | | | |
| g. Air density (~~upper-air~~, surface) | - 218 | | | | | | | |
| h. Air temperature | + 10 | | | | | | | |
| i. Rotation of earth | — | | | | | | | |
| j. Trunnion height and earth's curvature | + 36. | | | | | | | |
| k. Powder index | | | | | | | | |
| l. Powder temperature | + 221 | | | | | | | |
| m. Erosion | | | | | | | | |
| n. Sum of e through m | + 33. | | | | | | | |
| o. Expected range (d+n) | 10133. | | | | | | | |
| p. Navigational range at instant of firing | 9950 | | | | | | | |
| q. Target motion | - 44 | | | | | | | |
| r. Error of MPI | + 40. | | | | | | | |
| s. Actual range (p+q+r) | 9946. | | | | | | | |
| t. ACTH in range (o−s) | + 187. | | | | | | | |

NOTES
- c Identify guns by turret or mount number and gun position, i. e., 1R, 2C, 3 all, etc.
- d Gun range is range table range corresponding to elevation of gun above horizontal plane.
- e through m and q compute, using methods explained in range table, erosion curves.
- f and g. Cross out either upper air or surface as applicable

One copy direct to BuOrd. This sheet not required for (a) Night Firings, (b) Local Control, (c) Basic Gunnery Exercise.

Figure 13–2.—(A) Front of Gunnery Sheet 4, computation of arbitrary correction to hit (ACTH).



GUNNERY SHEET 4
OPNAV-34 B-120 (Back) Nov 3-47

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

| ITEM (Tabulate range and change in range in yards) | SALVO No. 1 | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. | SALVO No. |
|---|---|---|---|---|---|---|---|---|
| u. Deflection used (mils) | + 3 | | | | | | | |
| v. Drift (yds.), (right) | + 71 | | | | | | | |
| w. Own ship's motion (yds.) | + 111 | | | | | | | |
| x. Wind (yds.) | + 39 | | | | | | | |
| y. Rotation of earth (yds.) | — | | | | | | | |
| z. 1,000 (v.+w.+x.+y.)÷s. (mils) | + 22 | | | | | | | |
| aa. Expected deflection MPI (u.+z.) (mils) | + 25 | | | | | | | |
| bb. Target motion (mils) | + 25 | | | | | | | |
| cc. Error of MPI (mils) | - 2 | | | | | | | |
| dd. Actual deflection MPI (bb.+cc.) (mils) | + 23 | | | | | | | |
| ee. ACTH in deflection (aa.−dd.) (mils) | + 2 | | | | | | | |

NOTES
- (u) through (y) and (bb), refer to range table, erosion curve.
- (bb) is: $\frac{\text{deviation for lateral motion of target, (yds.)}}{(p)+(q)}$
- (cc) is: $\frac{\text{error of MPI from center of target, (yds.)}}{(s)}$

U. S. GOVERNMENT PRINTING OFFICE : [illegible]

Figure 13–2.—(B) Back of Gunnery Sheet 4, computation of arbitrary correction to hit (ACTH).

In computing the ACTH in range, the computer sight angle is the basis of the problem in determining the gun range; that is, the range-table range corresponding to the elevation of the gun above the horizontal plane. To this range-table range, the errors in range caused by the factors affecting the initial velocity and the slight of the projectile are added, ALGEBRAICALLY, making EXPECTED RANGE, which is the theoretical distance the projectile SHOULD travel. Then the present (navigational) range, the actual target motion in range, and range MEAN POINT OF IMPACT (MPI), are added, making ACTUAL RANGE, the distance the projectile really traveled. ACTUAL RANGE and EXPECTED RANGE are then subtracted to find ARBITRARY CORRECTION TO HIT (ACTH), in range.

The computer deflection is the basis of the deflection problem. The errors caused by factors affecting the deflection of the MPI are added and converted to mils to find a total expected deflection error. This total is added to the computer deflection used to determine EXPECTED DEFLECTION MPI, the theoretical angular deflection of the MPI to the right or left of the line of sight. Actual target motion in deflection and the deflection error of the MPI are added to make up ACTUAL DEFLECTION MPI, the true angular distance the MPI lies to the right or left of the line of sight. Actual deflection and expected deflection are subtracted to find the ACTH, in deflection.

## LINE-BY-LINE EXPLANATION OF GUNNERY

The following detailed explanation of each line on the Gunnery Sheet 4 should make it possible for you to make out a Sheet 4 without any aid other than the necessary observer's data.

The headings at the top of the front of the sheet (fig. 13–2, part *A*) and the first three lines (*a*, *b*, and *c*) need no explanation. There is no computation involved; they are filled in from known data and data gathered by the observers at the time of firing.

LINE *d* GUN RANGE. Enter column 2*a* of the applicable range table, using computer sight angle reading, and read gun range for line *d* in column 1, interpolating as necessary. This point in the range table will be the point at which the table is entered to obtain data for the solution of the rest of the problem.

**Line *e*, own ship's motion.** Enter column 14 of the range table, finding change in range for motion of gun in plane of fire of 10 knots. The value is multiplied by $Yo$, the component of own ship's range motion in knots, and then divided by 10 to obtain error for line *e*. If the own ship's motion decreases the range, make the sign positive.

**Line *f*, true wind.** Enter column 13 of the range table, finding change in range for wind component in the plane of fire for 10 knots. This value is multiplied by $Yw$, the range component of true wind in knots, and then divided by 10 to obtain error for line *f*. If the $Yw$ component is such as to aid the flight of the projectile, make the sign positive.

**Line *g*, air density.** Enter nomogram in front of range table with barometric pressure, atmospheric temperature, and gun range. Read the range error in yards and enter this value in line *g*, using the sign indicated by the table.

**Line *h*, air temperature.** Enter column 12*a* of the range for minus 10° variation from standard temperature. Find the difference between the atmospheric temperature and standard atmospheric temperature (59°). This difference is multiplied by the value from column 12*a* and then divided by 10 to obtain the error for line *h*. If the temperature is less than 59°, make the sign positive.

**Lines *i* and *j*, rotation of the earth, trunnion height, and earth's curvature.** These may be omitted from calculations involving 5-inch and smaller guns, but will be found in the range tables for batteries in which they are required.

**Line *k*, powder index.** Find the erosion curve in the back of the range table which applies to the type of powder used. This curve will show if the powder index used will cause velocity loss. If there is no additional velocity loss due to the index used, enter 0 for line *k*. If there is a velocity loss given, note its value, and then enter column 10 to obtain change in range for a 10-foot-second increase in velocity. The velocity loss given in the erosion curve is multiplied by the value from column 10, and then is divided by 10 to obtain range error for line *k*. The sign is negative if the powder index causes a loss in velocity.

LINE *l*, POWDER TEMPERATURE. Find the difference between powder temperature and the standard powder temperature (90° F.). Multiply this difference by the constant 1.5, to obtain density change in foot-seconds. Convert this, with Velocity Change to Range Error in yards, for line *l*, using column 10 as in line *k*. The sign of the error is positive if the powder temperature is above 90° F.

LINE *m* EROSION. Refer to the erosion curve used in *k*. Enter the curve with the weight of the powder charge and the bore erosion-gage reading to obtain the velocity loss from range-table initial velocity. (If no bore erosion-gage reading is available, enter the applicable curve with weight of charge and bore enlargement in inches.) Convert this velocity change to a range error in yards for line *m*, using column 10 as in *k*. Make the sign negative except in the case of the 5″/38 range table, where the *I. V.* is 2600 *fs*, but the range table is based on a nominal velocity of 2500 *fs*. In this case, the sign is positive unless the velocity loss from 2600 *fs*, is over 100. Example of 5″/38 computation: If the erosion loss from the curve were 65 *fs*, the erosion error, line *m*, would be equal to $\frac{35 \times \text{col. } 10}{10}$ and would be positive.

Example of 5″/38 computation: If the erosion loss from the curve were 145 *fs*, the erosion error for line *m* would be equal to $\frac{45 \times \text{col. } 10}{10}$ and would be negative.

LINE *n* SUM OF *e* THROUGH *m*. This algebraic sum represents the total expected range error.

LINE *o*, EXPECTED RANGE. Find the algebraic sum of gun range and total expected range error. This range represents the theoretical distance the projectile *s* should travel.

LINE *p*, NAVIGATIONAL RANGE AT INSTANT OF FIRING. Enter the most accurate available navigational range. Usually this will be from a search radar or a nonfiring F. C. radar; otherwise use computer present range in line *p*.

**Line** *q*, **target motion.** Enter column 15 of the range table, finding change in range for action of target in plane of fire at 10 knots. This value is multiplied by *Yt*, component of target's range motion in knots, and then divided by 10 to obtain value for line *q*. If the target's motion increases the range, make the sign positive.

**Note:** The actual (not computer) target course and speed must be used when solving for *Yt* and *Xt*.

**Line** *r*, **error of MPI.** Compute the range error of the geometric center of the salvo from camera-party or rake information. Enter this value in line *r* and make the sign positive if the MPI is over.

**Line** *s*, **actual range.** Find the algebraic sum of present range, target motion in range, and error of the MPI. This value represents the mean distance the projectile(s) traveled.

**Line** *t* **ACTH in range.** Subtract actual range from expected range to find the arbitrary correction to hit in range.

**Line** *u*, **deflection used.** Subtract 500 from computer deflection counter reading to obtain value for line *u*. (Refer to fig. 13–2, part *B* or the back of Gunnery Sheet 4.)

**Line** *v*, **drift.** Enter column 6 of the range table, finding drift error in yards. Use the value in line *v*. The sign is always positive.

**Line** *w*, **own ship's motion.** Enter column 17 of the range table, finding yards deviation for lateral motion of gun perpendicular to the line of fire for a speed of 10 knots. This value is multiplied by *Xo*, the deflection component of own ship's motion, and then divided by 10 to obtain error for line *w*. If the *Xo* component carries the projectile to the right, the sign of the error is positive. If it carries it to the left, the sign is negative.

**Line** *x* **wind.** Enter column 16 of the range table, finding yards deviation for a lateral wind component of 10 knots. This value is multiplied by *Xw*, the deflection component of true wind in knots, and then divided by 10 to obtain error for line $x$. If the $Xw$ component causes the projectile to be deflected to the right, make the sign positive; to the left, make the sign negative.

LINE $y$ ROTATION OF THE EARTH. See lines $i$ and $j$.

LINE $z$ TOTAL EXPECTED DEFLECTION ERROR IN MILS. Find the algebraic sum of errors in lines $v$ through $y$. This is multiplied by 1,000 and divided by actual range in order to convert the error to mils.

LINE $aa$ EXPECTED DEFLECTION OF MPI. Find the algebraic sum of the deflection used and the expected deflection error. This represents the theoretical expected deflection to the right or left of the present line of sight.

LINE $bb$ TARGET MOTION. Enter column 18 of the range table, finding yards deviation for lateral motion of the target perpendicular to the line of fire for a speed of 10 knots. This value is multiplied by $Xt$, the deflection component of target's motion, and then divided by 10. This lateral motion in yards is multiplied by 1,000 and divided by the sum of present range and target motion in range, to convert the motion to mils for the value in line $bb$. If the target is moving to the right, make the sign positive; to the left, make the sign negative.

LINE $cc$ ERROR OR MPI. Compute the deflection error of the geometrical center of the salvo from the camera-party data. Multiply this error by 1,000 and divide the result by the actual range to find the value for line $cc$. If the error is to the right, make the sign positive; to the left, make the sign negative.

LINE $dd$ ACTUAL DEFLECTION. Find the algebraic sum of $bb$ and $cc$. This value represents the true angular distance in mils the MPI was to the right or left of the line of sight.

LINE $ee$ ACTH IN DEFLECTION. Subtract actual deflection from expected deflection to find arbitrary correction to hit in deflection.

## RAKE OBSERVATION

The RAKE is an instrument that permits the making of visual estimates of the range errors of the fall of shot. It is

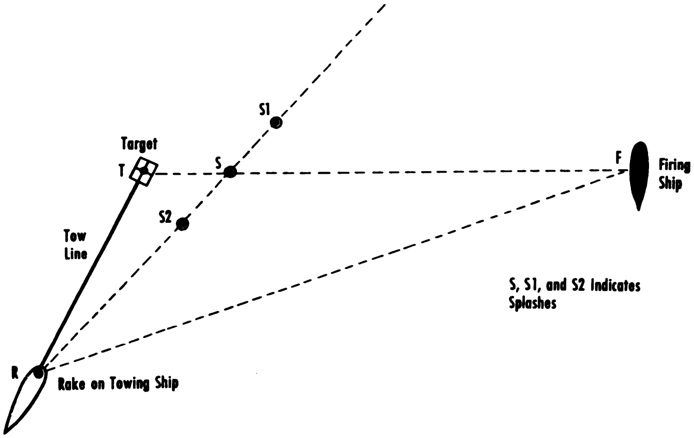


Figure 13–3.—The triangles measured by the rake.

used for the observation of day or night practices, and permits the immediate reporting of approximate range errors. In the daytime, rakes are also useful in assisting in the finding of splashes in triangulation photographs.

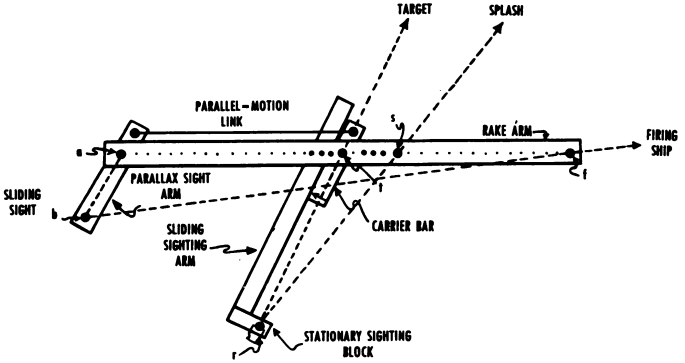


Figure 13—4.—Rake schematic, showing the rake triangles.

Operated from the towing ship by two operators, the rake measures distance by the geometric principle of similar triangles. The triangles being solved are RTF and RTS in figure 13–3. Figure 13–4 is a schematic of the rake alining the rake triangles .

To get the correct proportion of similar triangles on the rake, the length of the sighting arm and the position of the sliding sight peg must be set in accordance with the expected MEAN RANGE of fire and the distance from the rake to the target. On the rake, triangle *abf* (in fig. 13–4) corresponds to triangle RTF in figure 13–3, and triangle *rts* (in fig. 13–4) corresponds to triangle RTS in figure 13–3. Thus for setting the sliding sight:

$$\frac{ba}{\text{Distance from rake to tow } (RT)} = \frac{af}{\text{Mean range } (TF)}$$

and for setting the slide arm:

$$\frac{rt}{\text{Distance from rake to tow } (RT)} = \text{Rake scale (normally 1 inch equals 25 yards).}$$

While rake observations are being made, the rake must be kept properly alined. This is done by keeping the sight arm (*rt*) pointed at the target and by lining up the sliding sight (*b*) with the end peg of the rake and the firing ship.

With the rake properly alined and set, the rake estimation is made by sighting from the stationary sight to the splash. The position (*ts*) of the peg that lies on this splash line determines the approximate error of the splash from the target in range. With no deflection error:

$$\frac{\text{Error of the fall of shot } (TS)}{\text{Target towing ship distance } (RT)} = \frac{\text{Intercept on rake arm } (ts)}{\text{Length of sight arm } (rt)}.$$

The greatest error of the rake method of observing errors is caused by the necessary assumption that all the shells fall along the line from the firing ship to the target. Thus the range errors of $S$, $S1$, and $S2$ in figure 13–3 are considerably different, but to the rake observer they should appear to be the same.

Slight inaccuracies may also be introduced by incorrect graduations and improper alinement of the rake arm and sliding sighting arm.

## Operation—Offset Practice

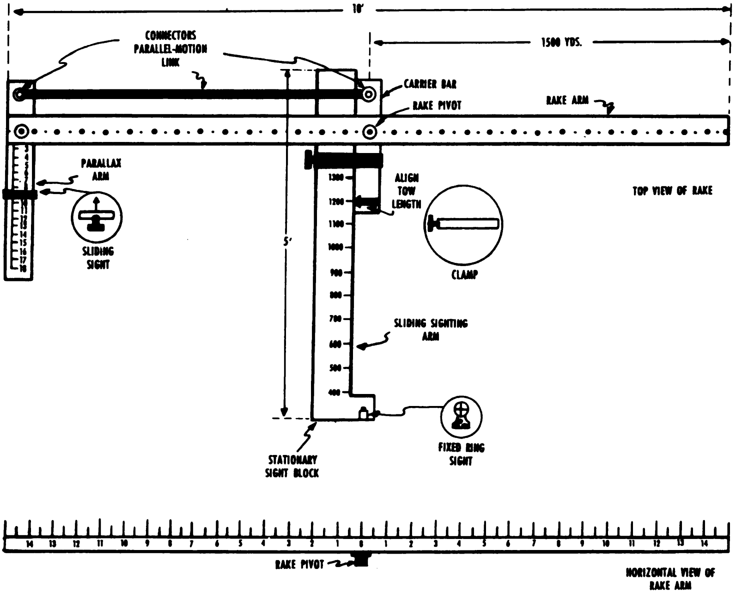
The rake may be used for estimating splash errors on an offset practice by setting and clamping the sight and sliding arm at an angle of 86° (angle *rtf* or angle *baf* in **fig.** 13–4). This is the correct angle for a 70-mil offset but must be changed if a different offset is used. For a given angular offset the sliding sight has but one position. The sighting-arm length must, however, be changed with the range to agree with the variable distance to the "target" from the target vessel.

## Description of a Standard Rake

The correct nomenclature for the parts of a standard rake (see figs. 13–4 and 13–5) is as follows: (1) rake arm, (2) sliding sighting arm, (3) parallax arm, (4) parallel-motion link, (5) fixed ring sight, (6) stationary sighting block, (7) sliding sight, (8) parallel-motion link connections, (9) sighting-arm carrier bar.

The rake is usually designed for mounting in a one-pounder cage stand; but, regardless of the mounting to be used, a cylindrical plug should be fitted to the underside of the rake to carry the large pivot pin passing through the sighting-arm carrier bar and through this plug. The pivot pin carries one washer under its head, one separation washer for each separate piece through which it passes, and a nut with a cotter pin at its upper end.

In order to obtain the greatest range of adjustment of the sliding sighting arm (fig. 13–5), together with compactness as a whole, the carrier bar is used. The sighting arm is thus offset by the width of the carrier bar, but the line of sight is brought back into the proper alinement by the use of the stationary sight block secured to the end of the sighting arm. The parallax arm and the sighting-arm carrier bar are extended forward of the point of their pivot with the rake arm by an appropriate amount, so that the parallel-motion link can be attached on the side of the rake arm away from the operator, thus eliminating any congestion or interference of the several parts of the instrument when settings of the stationary sight and the sliding sight are close to the rake arm, as will be the case during observations taken when a short towline is being used.



SCALE FOR 10' RAKE: 1" = 25 YARDS
SPLASH PEGS EVERY 50 YARDS
SPLASH MARKINGS EVERY 100 YARDS

Figure 13–5.—Working drawing of rake.

The sighting arm (fig. 13–5) is graduated for effective towline lengths from 400 to 1,300 yards, and is adjustable in its set length by means of the sighting arm clamp. The graduation representing the towline length is made coincident with the arrowhead pointer on the sighting-arm carrier bar. If any increase over 1,300 yards in towline length is anticipated upon construction, it will only be necessary to increase the length of the sighting arm by an appropriate amount.

## Rake Observation

The reading edge of the rake is beveled in order that the distinguishing marks may run as close as possible to the base of the pins and thus reduce to a minimum the possibility of confusing adjacent pins during the hasty observations necessary with the several shots of a large salvo.

The parallax arm is graduated in inches from its pivot point on the rake arm, so that the forward edge of the rectangular strap piece forming the base for the sighting pin is the reading edge.

By a very short and easy solution of similar triangles where approximate mean range of firing ship, towline length, and rake-arm length are known, the correct setting of the sliding sight is easily determined.

NOTE: The parallax arm is on the end of the rake away from the firing ship when the rake is set up, and is trained on the target from the towing ship ready for operation.

For maintaining the rake arm parallel to the line of fire, the operator at the sliding sight must aline the pin of the sliding sight and the pin on the far end of the rake arm with the firing ship.

## QUIZ

1. The data to be recorded by an observing party are found described in
   a. secret publications.
   b. Ordnance and Gunnery Manual.
   c. confidential publications.
   d. ship's organization plans.
2. Observing parties are necessary during practice firings in order to (Choose the best answer.)
   a. prevent casualties.
   b. collect data to be used later in determining the characteristics of the ship's battery.
   c. collect data to be used later in determining the ship's accuracy of performance.
   d. check the alinement of the battery.

3. What is the security classification of the data recorded by observers?
    a. Secret.
    b. Private-official.
    c. Confidential.
    d. Unclassified.
4. ACTH is computed on Gunnery Sheet Number
    a. 4.
    b. 3a.
    c. 6.
    d. 10.
5. What is the basis of the problem in determining expected gun range on Gunnery Sheet 4?
    a. Navigational range.
    b. Present range.
    c. Advance range.
    d. Computer sight angle.
6. How many operators are required to operate a rake properly in observing the fall of shot?
    a. One.
    b. Two.
    c. Three.
    d. Four.
7. The greatest error of the rake method of observing fall of shot is the assumption that
    a. all the shots fall along the line from the firing ship to the target.
    b. all the shots fall on the line from the towing ship to the target.
    c. all the shots fall in the same place.
    d. all the shots fall on a line from the firing ship to the towing ship.
8. Can the rake be used for estimating splash errors at an offset practice?
    a. No.
    b. Yes.
    c. Not unless the sighting arm is replaced with another of different construction.
    d. Only under certain ideal conditions.

# APPENDIX I

# ANSWERS TO QUIZZES

## CHAPTER 1

## THE AA FIRE-CONTROL SYSTEM—BALLISTICS

1. a. Zero.
2. b. With a three-dimensional cam.
3. c. Sight angle.
4. b. To the left.
5. a. Increased.
6. d. Rotates the cam.
7. b. Sight angle decreases.
8. a. Elevation decreases.
9. b. $Ds+B-Bw$.
10. d. $Xwg$.

## CHAPTER 2

## THE AA FIRE-CONTROL SYSTEM—OWN SHIP AND TARGET MOTION

1. Gun elevation order, gun train order, and fuze order.
2. Horizontal reference plane.
3. Own ship and target.
4. $Sh$ sin $A$.
5. By comparing generated and observed rates.
6. Three. $A$, $Sh$ and $dH$.
7. $Yo$ and $Yt$.
8. $X$ components.
9. $dR$, $RdE$, and $RdBs$.
10. Increases.
11. a. $T/cR$.
12. $Xo$ and $Xt$.
13. b. Unchanged.
14. Dead time.
15. b. $R2$.
16. a. Elevation.

## CHAPTER 3

# THE AA FIRE-CONTROL SYSTEM—GUN AND FUZE ORDERS

1. c. Vertical plane.
2. d. The intersection of the vertical plane containing the LOS with the deck plane.
3. a. *L*.
4. The functions of the inner, and outer gimbals are reversed. A stable element measures cross level with the outer gimbal and level with the inner gimbal.
5. c. Computer.
6. *Vz* and *Dz*.
7. a. Deck plane.
8. b. *Pe*, *Pv*, and *Ph*.
9. The difference between the angles $E2$ and $E+Vtw$ is $Vx$, the complementary error correction.

## CHAPTER 4

# THE AA FIRE-CONTROL SYSTEM—RATE CONTROL

1. It provides a faster rate solution.
2. By means of the elevation correction integrator and the bearing correction integrator.
3. The vertical plane through the target path.
4. Target angle (*A*).
5. Recalibration of the range rate ratio knob to read directly as range time constant.
6. Time (in seconds) required for a range rate error to be reduced to approximately 37% of its initial value.
7. By means of the air-surface switch and the sensitivity push button.
8. Automatic.
9. When the director first indicates that it is "on target."
10. 700 yds.
11. To simplify the task of the operating crew during target acquisition.
12. Maximum value of 8000 yds.

## CHAPTER 5

# THE AA FIRE-CONTROL SYSTEM—THE DIRECTOR

1. Director, computer, and stable element.
2. The director.
3. Director elevation, director train, and present range.
4. One which can be used against either aerial or surface targets.
5. *E'g*, *B'gr*, *Vs*, *Ds*, *F*, *Ph*, and *Pv*.
6. The stable element measures *Zd* by the outer gimbal and *L* by the inner gimbal. The stable vertical does just the opposite.
7. Manual, local, or normal.
8. By an input of *Zd* from the stable element.
9. d. Slewing motor.
10. Amplidyne.
11. c. Manual or automatic.
12. By shift levers located on handwheel brackets.
13. Train, elevation, and cross level.
14. Automatic.

## CHAPTER 6

# THE AA FIRE-CONTROL SYSTEM—THE COMPUTER

1. To double the limits of operation of those in the computer Mk 1.
2. They are taken along and at right angles to the line of sight.
3. The (*E*) transmitted by the target elevation potentiometer is used in the Indicator Mk 22 Mod 0 of the Radar Equipment Mk 25 Mod 2, during target acquisition.
4. Normal.
5. The time in seconds required for the range rate control mechanism to reduce a range rate error to approximately 37% of its initial value.
6. By depressing the sensitivity push button which opens the switch allowing the sensitivity mechanism to assume the maximum sensitivity position.
7. Normal operation only.
8. The trainer may start the time motor by closing his signal key or the computer operator may depress the time push button on the computer.
9. To effectively reduce oscillation in *R*2, *F*, and *E'g* lines.
10. To reduce the values of the output of the prediction multipliers to their original values. (This enables the use of the prediction section of the Mk 1 computer without redesigning it for the increased values.)

11. By momentarily shifting the range time constant knob to a high value, or by rotating the generated range crank in the out position.

## CHAPTER 7

# RELATIVE-RATE ANTIAIRCRAFT SYSTEMS

1. There is a concentric "no signal" circle inside the circular reticle at the center of the scope.
2. In main sweep.
3. By a gyro unit located in the director.
4. The cross traverse plane.
5. To establish a stable reference plane.
6. The rate of change or present range.
7. To convert lead angles into their equivalent angles in deck coordinates.
8. Range; range rate to computers and electrical signals to the director for tracking obscured targets.
9. To compute projectile time of flight, superelevation, drift, range rate, and fuze order.
10. *U* or average velocity of the projectile.
11. On the gun.
12. Manually by the director pointer.
13. About 30° in any direction.
14. The wind transmitter.
15. Two seconds.
16. Four.
17. The securing locks incorporate a protective microswitch that cuts out power to the amplidyne generators when either lock is in the secured position.
18. Radar-optical switch.

## CHAPTER 8

# GENERAL MAINTENANCE

1. Repair parts or storage.
2. Energized.
3. Rust, oxidation, or corrosion.
4. Insulation.

5. Rust. Wide. Low or slow.
6. Tenders. Repair ships. Navy yards.
7. Bureau of Ordnance.
8. Fire-control gray and black enamels.
9. Handle with care—delicate instrument.
10. Synchro.
11. Static.
12. Integrators or rate-generation mechanisms.
13. Intermediate.
14. Manual time crank.
15. Dummy director. Error recorder.
16. Dry.

## CHAPTER 9

## ORDNANCE ALINEMENT

1. c.
2. c.
3. d.
4. a.
5. d.
6. d.
7. a.
8. a.
9. b.
10. c.
11. b.
12. When two points well separated from each other on the centerline are visible to each other.
13. Procurement and interpretation of roller-path data.
14. Shore transit method and the deck transit method.
15. Polar coordinate.
16. The transit method and the plumb-bob method.

## CHAPTER 10

## SPOTTING GUNFIRE

1. b.
2. b.
3. d.
4. c.
5. a.
6. b.
7. a.
8. b.
9. c.
10. d.

## CHAPTER 11

# NAVAL GUNFIRE SUPPORT

1. To support the seizure of the objective by reducing or neutralizing shore installations; to stop enemy troops that oppose our forces both prior to and during the landing; and to assist the advance of our troops after the landing has been made.
2. Mobility.
3. Prior to, during, and after the landing.
4. Slow, deliberate, accurate gunfire delivered for the purpose of destroying a target, usually a material object.
5. Sporadic gunfire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement.
6. When requested by troop units ashore.
7. In direct fire the target is used as a point of aim; in indirect fire, some other point is used.
8. The nature and size of the target to be engaged and the proximity of friendly troops to the target determine the selection of gun or weapon.
9. Because of their maneuverability.
10. They have a great explosive content at the expense of penetrative ability and produce a heavy blasting and shrapnel effect.
11. Prelanding bombardment, support during the landing, and support for troop advancement ashore.
12. A forward slope decreases it, while a reverse slope increases it.
13. Drift as target speed and the direction of the set is reversed and introduced as target course.
14. 1,000 meters square.
15. As soon as the MPI has been spotted to hit Point OBOE.
16. To keep an exact check upon the ship's position so as to determine ranges and bearings to targets designated for indirect fire.
17. Increase the range or use reduced-velocity charges at a shorter range to obtain the selected angle of fall.
18. Under the old system frequent errors in spotting were introduced because of improper orientation of the spotter with reference to the gun-target line.

## CHAPTER 12

# THE DUMMY DIRECTOR AND ERROR RECORDER—TEST EQUIPMENT

1. b. Dynamic accuracy tests.
2. c. Three synchro circuits.

3. b. Both inputs to the component integrator.
4. Size 1*G* synchro generator.
5. Size 1*DG* synchro differential generator.
6. Mount under test and one from the dummy director.
7. Vernier and drum-type gunner's quadrants.
8. d. Adjusting screw.
9. c. 1,000 ohms per volt.
10. b. Block d. c.
11. c. Open the circuit and discharge the capacitor.
12. Transconductance test.
13. Emission and short tests.
14. a. The equipment was properly designed and was at one time operative.
    b. Failure is usually due to the failure of a capacitor, resistor, or wiring.
    c. These items are usually subject to complete failure rather than a slow change in characteristics, as occurs with vacuum tubes.

## CHAPTER 13

# OBSERVATION AND ANALYSIS OF GUNNERY EXERCISES

1. c.
2. c.
3. c.
4. a.
5. d.
6. b.
7. a.
8. b.

# APPENDIX II

# FIRE-CONTROL SYMBOLS AND NOMENCLATURE

## PART I

### For the Antiaircraft Fire-Control problem as Solved by the MK 37 Director System

In the definitions given below the following terms are understood:

1. The term "line of sight" is used to designate the line of sight from the director to the target.
2. The term "deck plane" means the standard reference plane of the ship.
3. The term "horizontal plane" refers to the horizontal plane through the director sights. The solution given by the computer is based upon this plane.

| | |
|---|---|
| A | Target angle. Angle between vertical plane through direction of motion of target with respect to earth and vertical plane through line of sight, measured in the horizontal plane clockwise from direction of motion. ($A = 180° + B - Ct$) |
| B | True target bearing. Angle between North-South vertical plane and vertical plane through line of sight, measured in the horizontal plane clockwise from North. ($B = Br + Co$) |
| $\Delta cB$ | Increment of generated true bearing. |
| jBc | Linear deflection rate correction. Rate control correction primarily affecting linear deflection rate. |
| Br | Relative target bearing. Angle between vertical plane through fore and aft axis of own ship and vertical plane through line of sight, measured in the horizontal plane clockwise from bow. ($Br = B'r + jB'r$) |
| cBr | Generated relative target bearing. Relative target bearing generated by computer as opposed to relative target bearing derived from director train. ($cBr = c\Delta Br + jBr$) |
| $\Delta cBr$ | Increment of generated relative target bearing. ($\Delta cBr = \Delta cB - Co$) |
| jBr | Initial or corrective setting of generated relative target bearing. |

| | |
|---|---|
| dBs | Angular bearing rate, measured in slant plane containing line of sight and perpendicular to vertical plane through line of sight. (Does not exist separately in mechanism). |
| Bw | Wind direction. Angle between North-South vertical plane and direction from which wind is blowing, measured in the horizontal plane clockwise from North. |
| Bwg | Predicted wind angle. Angle between direction from which wind is blowing and vertical plane through line of fire (approximately), measured clockwise in the horizontal plane from direction from which wind is blowing. $(Bwg = Bws + KDs)$ |
| Bws | Wind angle. Angle between direction from which wind is blowing and vertical plane containing line of sight, measured clockwise in the horizontal plane from direction from which wind is blowing. $(Bws = B - Bw)$ |
| B′gr | Gun train order (uncorrected for parallax). Ordered angle between fore and aft axis of own ship and plane through gun axis perpendicular to deck plane, measured in deck plane clockwise from bow, without correction for horizontal parallax. $(B'gr = B'r + Dd)$ |
| B′r | Director train. Angle between fore and aft axis of own ship vertical plane through line of sight measured in deck plane clockwise from bow. |
| △cB′r | Increment of generated director train. (bearing correction). $\triangle(cB'r = \triangle cBr - jB'r)$ |
| jB′r | Correction to director train for effect of deck tilt. (Correction to refer director train to the horizontal plane.) |
| Co | Ship course. Angle between North-South vertical plane and vertical plane through fore and aft axis of own ship, measured in the horizontal plane clockwise from North. |
| Ct | Target course. Angle between North-South vertical plane and vertical plane through direction of motion of target with respect to earth, measured in the horizontal plane clockwise from North. |
| Dd | Deck deflection. Angle representing total deflection in deck plane; equal to gun train order minus director train. $(Dd = jDd + Dz)$ |
| jDd | Partial deflection in deck plane. |
| Dfs | Drift. Lateral deflection angle due to drift of projectile, measured in slant plane through advance position of target. $(Dfs = K(Vf + Pe + Vfm - K_1)$ |
| Dj | Deflection spot. |
| Ds | Sight deflection. Angle between vertical plane through line of sight and vertical plane through axis of gun, measured in |

| | |
|---|---|
| | plane perpendicular to vertical plane through line of sight at angle Vtw above line of sight. (Positive if gun is trained right from line of sight). (This is an approximation of sight deflection as defined in *O.D.* 3,447.) ($Ds = Dtwj - Dfs$) |
| Dt | Deflection to compensate for relative movement of own ship and target. (does not exist separately in mechanism) |
| Dw | Deflection to compensate for effect of apparent wind on projectile. (does not exist separately in mechanism) |
| Dtw | $Dt + Dw$. |
| Dtwj | $Dtw + Dj$. |
| Dz | Approximate correction in train due to cross level. |
| E | Target elevation. Angle between line of sight and the horizontal plane, measured in vertical plane through line of sight. ($E = Eb - L$) |
| cE | Generated target elevation. Target elevation generated by computer as opposed to that derived from director elevation. ($cE = \Delta cE + jE$) |
| $\Delta cE$ | Increment of generated elevation. |
| $\Delta cE + L + \frac{Zd}{30}$ | Increment of generated director elevation compensated for roll of director sights in cross level. (elevation correction) |
| dE | Angular elevation rate. (does not exist separately in mechanism) |
| jE | Initial or corrective setting of generated elevation. |
| Eb | Director elevation. Elevation of director line of sight above deck plane, measured in vertical plane through line of sight. |
| jEc | Linear elevation rate correction. Rate-control correction primarily affecting linear elevation rate. |
| E'g | Gun elevation order. Ordered elevation of gun above deck plane, measured in plane through gun axis perpendicular to deck plane. (includes parallax correction for vertical base but not for horizontal base) |
| $E_2$ | Predicted target elevation. ($E_2 = E + V$) |
| F | Fuze setting order. |
| H | Height. Vertical distance of target above the horizontal plane through director sights. |
| dH | Rate of climb (vertical). |
| jHc | Rate of climb correction. Rate-control correction primarily affecting rate of climb. |
| I. V. | Initial velocity. |
| K, $K_1$, $K_2$ etc. | Constants. Two or more constants in the same expression are distinguished by numbers. |

| | |
|---|---|
| L | Level angle. Angle between deck plane and the horizontal plane, measured in vertical plane through line of sight. (positive, when deck toward target is tilted down) |
| Pe | Parallax in elevation due to 10-yard vertical base. |
| Ph | Parallax in train due to 100-yard horizontal base. |
| Pv | Parallax in elevation due to 100-yard horizontal base. |
| R | Observed present range. |
| cR | Generated present range. |
| 1/cR | Inverse generated present range. |
| $\triangle$cR | Increment of generated present range. (range correction) |
| dR | Direct range rate. (along line of sight) |
| jdR | Direct range rate correction. Rate-control correction primarily affecting direct range rate. |
| jR | Initial or corrective setting of generated range. |
| jRc | Correction applied to generated range during rate control. |
| dRh | Horizontal range rate. ($dRh = -Yo - Yt$) |
| jdRh | Horizontal range rate correction. Rate-control correction primarily affecting horizontal range rate. |
| Rj | Range spot. (affects advance range only) |
| Rm | Correction to range prediction for change in I.V. from 2,550 foot-seconds. |
| dRm | Correction to prediction range rate for change in I.V. from 2,550 foot-seconds. |
| dRs | Prediction range rate. Range rate corrected for effect of deflection and elevation rates, and for change in I.V. from 2,550 foot-seconds. ($dRs = dR + dRxe + dRm$) |
| Rt | Range prediction to compensate for relative movement of own ship and target. (does not exist separately in mechanism) |
| Rw | Range prediction to compensate for effect of apparent wind on projectile. (does not exist separately in mechanism) |
| Rtw | $Rt + Rw$. (does not exist separately in mechanism) |
| Rtwm | Range prediction. ($Rtwm = Rtw + Rm$) |
| dRxe | Correction to prediction range rate for deflection and elevation rates. |
| $R_2$ | Advance (or predicted) range. ($R_2 = cR + Rtwm + Rj$) |
| $R_3$ | Fuze range. ($R_3 = R_2 + RTg$) |
| RdBs | Linear deflection rate. Components of own ship and target motion perpendicular to line of sight and parallel to the horizontal plane. ($RdBs = Xo + Xt$) |

| | |
|---|---|
| RdE | Linear elevation rate. Components of own ship and target motion perpendicular to line of sight and contained in vertical plane through line of sight. |
| RTg | Correction in fuze range for dead time. (RTg = K · Tg · dR) |
| Sh | Horizontal ground speed of target. |
| So | Ship speed. |
| Ss | Diving speed of target. Speed along line of sight, or direct range rate. |
| Sw | True wind speed. |
| T | Time (generated by regulated time motor). |
| T/cR | Time divided by generated range. |
| Tf | Time of flight. |
| $TF/R_2$ | Time of fiight divided by advance range. |
| Tg | Dead time. Time in seconds between setting fuze and firing projectile. |
| V | Elevation prediction. (V = Vtw − Vx + Vj) |
| Vf | Superelevation. Angle gun must be elevated above predicted target elevation to compensate for curvature of trajectory in vertical plane. |
| Vfm | Correction to superelevation for change in initial velocity from 2,550 foot-seconds. |
| Vj | Elevation spot. |
| Vs | Sight angle. Difference between elevation of gun axis above the horizontal plane and elevation of line of sight above the horizontal plane: measured in vertical plane through gun axis. This angle is positive if axis of gun is above line of sight. (This is an approximation of sight angle as defined in *O.D.* 3,447.) (Vs = V + Vf + Pe + Vfm) |
| Vt | Elevation prediction to compensate for relative movement of own ship and target. (does not exist separately in mechanism) |
| Vw | Elevation prediction to compensate for effect of apparent wind on projectile. (does not exist separately in mechanism) |
| Vtw | Vt + Vw. |
| Vx | Complementary error correction. Correction in gun elevation order due to deflection prediction. |
| Vz | Trunnion tilt elevation correction. Correction in gun elevation order due to cross level. |
| WrD | Component of apparent wind velocity affecting deflection prediction. (WrD = − Xo − Xwg) |
| WrE | Component of apparent wind velocity affecting elevation prediction. (WrE = Ywgr sin K · $E_2$) |

| | |
|---|---|
| WrR | Component of apparent wind velocity affecting range prediction. (WrR = Ywgr cos K · $E_2$) |
| Xo | Horizontal component of own ship velocity perpendicular to vertical plane through line of sight. (Xo = So sin Br) |
| Xt | Horizontal component of target velocity perpendicular to vertical plane through line of sight. (Xt = Sh sin A) |
| Xwg | Horizontal component of true wind velocity, approximately perpendicular to vertical plane through line of fire. (Xwg = Sw sin Bwg) |
| Yo | Horizontal component of own ship velocity in vertical plane through line of sight. (Yo = So cos Br) |
| Yt | Horizontal component of target velocity in vertical plane through line of sight. (Yt = Sh cos A) |
| Ywg | Horizontal component of true wind velocity, approximately in vertical plane through line of fire. (Ywg = Sw cos Bwg) |
| Ywgr | Horizontal component of apparent wind velocity, approximately in vertical plane through line of fire. (Ywgr = Yo + Ywg) |
| **Zd** | Cross-level angle. Angle of roll of deck about line which is the intersection of deck plane with vertical plane through line of sight. (positive if, when facing target, deck at left is tilted down). |

# PART 2

# FIRE-CONTROL SYMBOLS AND NOMENCLATURE

**For the Star-Shell Problem as solved by the Director System Mk 37**

| | |
|---|---|
| B'grn | Computed star-shell gun train order not including star-shell deflection spot. ($B'grn = B'gr + Dtown$) |
| B'grjn | Star-shell gun train order. Gun train order for gun firing star shells. ($B'grjn = B'grn + B'jn$) |
| B'jn | Star-shell deflection spot. |
| Dtown | Star-shell deflection. Deflection to compensate for movement of target, ship and star across line of sight during one-half life of star (30 seconds). $(Dtown = 1/10\ jDwn\ (Wrd = KRdBs)$ |
| jDwn | Angular movement of star during 30 seconds for a star-shell deflection rate of 10 knots. ($jDwn = K/R2n$) |
| E'gn | Computed star-shell gun elevation order not including star-shell elevation spot. ($E'gn = E'g + jVn$) |
| E'gjn | Star-shell gun elevation order. Gun elevation order for gun firing star shells. ($E'gjn = E'gn + E'jn$) |
| E'jn | Star-shell elevation spot. |
| Fn | Star-shell fuze setting order. ($Fn = f(R2n)$) |
| R2n | Star-shell range. Horizontal advance range to star-shell burst. ($R2n = R2 + 1000 + Rjn$) |
| Rjn | Star-shell range spot. |
| Vn | Star-shell sight angle. Computed vertical elevation of gun axis above horizon. Does not exist separately in mechanism. |
| jVn | Sight angle correction. Difference between sight angle for gun firing star-shells and for gun firing service projectiles. |
| WrD+KRdBs | Star-shell deflection rate. Linear rate at which star moves across line of sight. |

# APPENDIX III

# QUALIFICATIONS FOR ADVANCEMENT IN RATING

## FIRE CONTROL TECHNICIANS (FT)

### RATING CODE NO. 0800

## General Service Rating

### Scope

Fire control technicians maintain and repair fire control systems, including fire control radars and target designation equipment; make detailed mechanical, electrical, and electronic casualty analyses; test, operate, clean, lubricate, inspect, adjust, and calibrate fire control units; remove, repair, replace, and install, or reassemble fire control components and systems; make transmission, computing, and rate tests on fire control systems; boresight guns and aline guns and fire control systems.

## Emergency Service Ratings

Fire Control Technicians A (Automatic Directors), Rating Code No. 0804 ........................................ **FTA**

Maintain and repair fire control systems such as Marks 37, 56, 67, Gunars, surface fire control systems for caliber 6″ and above, and associated equipment.

Fire Control Technicians M (Manually Controlled Directors), Rating Code No. 0802 ........................................ **FTM**

Maintain and repair fire control systems such as Marks 52, 57, and 63, and Mark 51 director and associated equipment.

Fire Control Technicians U (Underwater), Rating Code No. 0803 ........................................ **FTU**

Maintain and repair underwater fire control systems or individual components thereof, and associated equipment.

Fire Control Technicians G (Missile Guidance Systems), Rating Code No. 0801 ........................................ **FTG**

(To be determined.)

## Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classifications, NavPers 15105 (Revised), codes FT–1100 to FT–1199.

Ch. No. 2

| *Qualifications for Advancement in Rating* | *Applicable Rates* | | | |
|---|---|---|---|---|
| 100 PRACTICAL FACTORS | FT | FTA | FTM | FTU |
| 101 OPERATIONAL | | | | |
| 1. Demonstrate method of resuscitating a man unconscious from electrical shock and treating for electrical burns | 3 | 3 | 3 | 3 |
| 2. Read dials and set operating controls to predetermined values on fire control equipment | 3 | 3 | 3 | 3 |
| 3. Demonstrate, on fire control equipment to which assigned, operating procedures and techniques as required to: | | | | |
| a. Perform operator's adjustments | 3 | 3 | 3 | 3 |
| b. Perform transmission, computing, and rate tests, and report and record results | 2 | 2 | 2 | 2 |
| 4. Demonstrate, on target designation equipment of own ship, operating procedures and techniques required to: | | | | |
| a. Perform operator's adjustments | 3 | 3 | 3 | -- |
| b. Test and interpret qualitative performance of designate and repeat-back channels | 2 | 2 | 2 | -- |
| 5. Demonstrate operating procedures and techniques on fire control equipment to which assigned, as required to train battle station and watch standing operators | C | C | C | C |
| 6. Compute ballistics, using standard forms and work sheets | C | C | C | -- |
| 7. Demonstrate operating procedures and techniques on target designation equipment or system of own ship as required to train battle station and watch standing operators | C | C | C | -- |
| 8. Compute corrections to compensate for operator and rangefinder errors | C | C | -- | -- |
| 102 MAINTENANCE AND/OR REPAIR | | | | |
| 1. Identify electrical and mechanical symbols used in schematic diagrams of fire control equipment, excluding radar | 3 | 3 | 3 | 3 |
| 2. Identify capacitors and resistors by RMA color codes | 3 | 3 | 3 | 3 |

| Qualifications for Advancement in Rating | Applicable Rates | | | |
|---|---|---|---|---|
| | FT | FTA | FTM | FTU |
| 102 MAINTENANCE AND/OR REPAIR—Continued | | | | |
| 3. Lubricate fire control equipment in accordance with lubrication charts | 3 | 3 | 3 | 3 |
| 4. Make tests of electrical fire control circuits for continuity, grounds and short circuits, and make repairs as necessary | 3 | 3 | 3 | 3 |
| 5. Inspect and clean commutator and slip ring assemblies and replace brushes | 3 | 3 | 3 | 3 |
| 6. Make prescribed electronic tests of servo and computing circuits, using multimeters, tube testers, and cathode ray oscilloscopes, and report results | 3 | 3 | 3 | 3 |
| 7. Make operator's adjustments and checks to fire control radars | 3 | 3 | 3 | -- |
| 8. Conduct shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles | 3 | 3 | 3 | -- |
| 9. Identify electronic symbols used in schematic diagrams of fire control equipment | 2 | 2 | 2 | 2 |
| 10. Trace circuits through fire control and sound-powered telephone switchboards | 2 | 2 | 2 | 2 |
| 11. Perform all tests and adjustments necessary for proper operation of servo and computing circuits. Test synchros, interconnecting circuits, and switchboards and set synchros to electrical zero | 2 | 2 | 2 | 2 |
| 12. Prepare a gun, director station, or target designation system for battery alinement (afloat) by alining synchros and setting mechanical dials to reference points | 2 | 2 | 2 | -- |
| 13. Make internal adjustments and calibrations to fire control radars | 2 | 2 | 2 | -- |
| 14. Make standard electronic tests of radar circuits, using signal generators, multimeters, tube testers, and cathode ray oscilloscopes, and report results | 2 | 2 | 2 | -- |

| *Qualifications for Advancement in Rating* | | *Applicable Rates* | | | |
|---|---|---|---|---|---|
| | | FT | FTA | FTM | FTU |
| 102 | MAINTENANCE AND/OR REPAIR—Continued | | | | |
| | 15. Perform all shipboard maintenance on rangefinders not requiring the services of an opticalman | 2 | 2 | -- | -- |
| | 16. Prepare underwater fire control systems for battery alinement (afloat) by alining synchros and setting mechanical dials to reference points | -- | -- | -- | 2 |
| | 17. Trace circuits and test synchros and servo mechanisms and make replacements, adjustments, and repairs | 1 | 1 | 1 | 1 |
| | 18. Test, remove, replace, and adjust mechanical parts of fire control and torpedo control equipment | 1 | 1 | 1 | 1 |
| | 19. Analyze failures and make repairs to servo and computing circuits | 1 | 1 | 1 | 1 |
| | 20. Lubricate and perform shipboard adjustments to gyroscopes used in fire control equipment | 1 | 1 | 1 | 1 |
| | 21. Conduct battery alinement tests and evaluate results | 1 | 1 | 1 | -- |
| | 22. Boresight guns and aline guns, directors, fire control radar antennas, torpedo fire control director, and indicators on tube mount, and target designation equipment. Test firing cut-out devices for proper operation | 1 | 1 | 1 | -- |
| | 23. Perform all tests and adjustments necessary for proper operation of radar circuits | 1 | 1 | 1 | -- |
| | 24. Aline underwater fire control systems. Test firing and firing cut-out devices for proper operation | -- | -- | -- | 1 |
| | 25. Analyze results of transmission, alinement, computer, and rate tests to determine need for adjustment, replacement of parts, or repairs | C | C | C | C |
| | 26. Conduct all electrical tests on a complete fire control system | C | C | C | C |
| | 27. Analyze failures and make repairs to target designation equipment | C | C | C | -- |

## Qualifications for Advancement in Rating—Continued

| Qualifications for Advancement in Rating | | FT | FTA | FTM | FTU |
|---|---|---|---|---|---|
| 102 | MAINTENANCE AND/OR REPAIR—Continued | | | | |
| | 28. Conduct battery alinement and compute and apply corrections | C | C | C | -- |
| | 29. Repair mechanical parts of fire control and torpedo control equipment excluding lathe and milling machine work | C | C | C | -- |
| | 30. Analyze failures and make repairs to fire control radars | C | C | C | -- |
| | 31. Analyze results of dummy director and error recorder tests and effect necessary repairs and adjustments | C | C | C | -- |
| | 32. Repair mechanical parts of underwater fire control equipment excluding lathe and milling machine work | -- | -- | -- | C |
| | 33. Conduct underwater fire control alinement and compute and apply corrections | -- | -- | -- | C |
| 103 | ADMINISTRATIVE AND/OR CLERICAL | | | | |
| | 1. Keep rough logs of periodic tests and maintenance | 3 | 3 | 3 | 3 |
| | 2. Make failure reports and keep ordnance histories | 2 | 2 | 2 | 2 |
| | 3. Use Catalog of Navy Material, BuOrd section | 2 | 2 | 2 | 2 |
| | 4. Maintain a Current Ship's Maintenance Project (CSMP) and prepare naval shipyard or tender work request or job order | C | C | C | C |
| | 5. Maintain supplies and spare parts and obtain replacements | C | C | C | C |
| 200 | EXAMINATION SUBJECTS | | | | |
| 201 | OPERATIONAL | | | | |
| | 1. Interpret and interpolate a dial setting into minutes, degrees, yards, or mils | 3 | 3 | 3 | 3 |
| | 2. Given course and speed of own ship, surface target, and true wind, solve analytically for range rate and deflection rate | 2 | 2 | 2 | -- |
| | 3. Given course and speed of own ship and target, solve analytically for range rate and deflection rate | -- | -- | -- | 2 |

| | *Qualifications for Advancement in Rating* | *Applicable Rates* | | | |
|---|---|---|---|---|---|
| | | FT | FTA | FTM | FTU |
| 201 | OPERATIONAL—Continued | | | | |
| | 4. Given course and speed of own ship, air target, and true wind, solve analytically for range rate and deflection rate | 1 | 1 | 1 | -- |
| | 5. Variables and constants of initial ballistics | C | C | C | -- |
| | 6. Elements of the air and surface fire control problems | C | C | C | -- |
| | 7. Operating principles of stereo rangefinders. Methods used to measure operator and rangefinder errors and methods used to compute corrections | C | C | -- | -- |
| | 8. Variables and constants of underwater ballistics | C | -- | -- | C |
| | 9. Elements of underwater fire control problems | C | -- | -- | C |
| 202 | MAINTENANCE AND/OR REPAIR | | | | |
| | 1. Types of information shown and meanings of electrical and mechanical symbols used in schematic diagrams of fire control equipment, excluding radar and fire control quantities | 3 | 3 | 3 | [illegible] |
| | 2. RMA color coding systems for capacitors and resistors | 3 | 3 | 3 | 3 |
| | 3. Precautions to be observed in lubricating fire control equipment | 3 | 3 | 3 | 3 |
| | 4. Methods and equipment used in electrical tests for continuity, grounds, and short circuits | 3 | 3 | 3 | 3 |
| | 5. Methods of testing resistors, potentiometers, coils, transformers, capacitors, and vacuum tubes and the application of each in voltage amplifier, phase invertor, power supply, oscillator, power amplifier, and rectifier circuits. Recognize electronic stages, power supply circuits, and coupling circuits | 3 | 3 | 3 | 3 |
| | 6. Function of each of the elements in gas filled, electron, and cathode ray tubes | 3 | 3 | 3 | 3 |

| | *Qualifications for Advancement in Rating* | *Applicable Rates* | | | |
|---|---|---|---|---|---|
| | | FT | FTA | FTM | FTU |
| 202 | MAINTENANCE AND/OR REPAIR—Continued | | | | |
| | 7. Calculate current, voltage, phase angle, impedance, and resistance in series and parallel circuits containing not more than a combination of four elements | 3 | 3 | 3 | 3 |
| | 8. Purposes of the following fire control radar operator's adjustments and checks: intensity, sweep, focus, centering, receiver gain, receiver tuning, video gain, modulator frequency, range slew, range and train and elevation zero checks | 3 | 3 | 3 | -- |
| | 9. Properties of free and restrained gyroscopes and purpose of damping | 3 | 3 | 3 | -- |
| | 10. Purpose and interpretation of shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles | 3 | 3 | 3 | -- |
| | 11. Purposes of transmitting, computing, and rate tests | 2 | 2 | 2 | 2 |
| | 12. Types, operating principles, and application of switching gear used in fire control and sound-powered switchboards | 2 | 2 | 2 | 2 |
| | 13. Characteristics and use of synchros and methods of setting to electrical zero | 2 | 2 | 2 | 2 |
| | 14. Operating principles (excluding knowledge required *only* in research, engineering and manufacture) of the following: tuned coupling circuits, impedance matching, cathode followers, modulators and demodulators, oscillators, phase shifters, mixers, heterodyning, automatic gain control, frequency modulation, discriminators, automatic frequency control, integration and differentiation, counting circuits, sawtooth generators, multivibrators, limiters, peakers, clampers, and half- and quarter-wave antennas | 2 | 2 | 2 | 2 |

| | *Qualifications for Advancement in Rating* | *Applicable Rates* | | | |
|---|---|---|---|---|---|
| 202 | MAINTENANCE AND/OR REPAIR—Continued | FT | FTA | FTM | FTU |
| | 15. Methods of making gain, phase, balancing, bias, and zeroing adjustments of servo loops found in computing and power-drive circuits | 2 | 2 | 2 | 2 |
| | 16. Use of tram bar, method of setting synchros to electrical zero, and method of positioning shafts by adjustable couplings | 2 | 2 | 2 | 2 |
| | 17. Types of information shown and meanings of electronic symbols used on schematic diagrams of fire control equipment, excluding symbols for fire control quantities | 2 | 2 | 2 | 2 |
| | 18. Types, application, and operating principles of electromechanical servo mechanisms | 1 | 1 | 1 | 1 |
| | 19. Purpose, operating principles, and adjustments of basic fire control mechanisms | 1 | 1 | 1 | 1 |
| | 20. Operating principles of computing circuits, servo loops, and power-drive circuits | 1 | 1 | 1 | 1 |
| | 21. Method of mounting and alining a boresight telescope on a gun. Purpose and method of alining sights to gun bore. Purpose and method of checking a director to a reference plane and reference point. Quantities set on inclination compensators. Methods to conduct train and elevation checks (afloat) | 1 | 1 | 1 | -- |
| | 22. Purpose and operating principles of the following radar circuits: transmitter, video amplifier, modulation generator, range unit, indicator unit, echo box, dummy antenna, power supply, wave guides, antennas, voltage regulator, transmission lines, IF amplifier, RF amplifier, or preselector | 1 | 1 | 1 | -- |
| | 23. Method of setting up and purpose of dummy director and error recorder tests; information obtained and interpretation of results | 1 | 1 | 1 | -- |

# Qualifications for Advancement in Rating—Continued

| | *Qualifications for Advancement in Rating* | *Applicable Rates* | | | |
|---|---|---|---|---|---|
| | | FT | FTA | FTM | FTU |
| 202 | MAINTENANCE AND/OR REPAIR—Continued | | | | |
| | 24. Method of alining underwater fire control systems | C | -- | -- | 1 |
| | 25. Purpose and method of the following radar checks: double echo receiver sensitivity, standing wave ratio, and transmitted power level | C | C | C | -- |
| | 26. Methods used in battery alinement (afloat and drydock). Use of gunner's quadrant. Method and purpose of static alinement. Principles involved in establishing bench mark and tram points. Method of computation of roller path inclination from horizon checks. Methods of train and elevation checks (afloat) | C | C | C | -- |
| | 27. Relationship of electrical and mechanical inputs and outputs of a radar, rangefinder, director, computer, stable element, and gun mount of a dual purpose battery | C | C | C | -- |
| 203 | ADMINISTRATIVE AND/OR CLERICAL | | | | |
| | 1. Types, purpose of, and entries made in rough logs | 3 | 3 | 3 | 3 |
| | 2. Purposes and types of entries made in failure reports and ordnance histories | 2 | 2 | 2 | 2 |
| | 3. Types of information found in the following publications: Ordnance Pamphlets, Ordnance Data, Ordnance Circular Letters, Ordnance Handling Instructions, Ordnance Modification Instructions, Ordnance Material Letters, and Ordnance Alterations | 2 | 2 | 2 | 2 |
| | 4. Purpose and scope of the BuOrd Manual as stated in Chapter 1 | 1 | 1 | 1 | 1 |
| | 5. Information shown in Current Ship's Maintenance Project (CSMP), naval shipyard, tender work request, or job order | C | C | C | C |
| | 6. Physical requirements for rangefinder operators | C | C | -- | -- |

## APPENDIX IV

# TRIGONOMETRIC FUNCTIONS OF AN ANGLE

| Angle | Sin | Cos | Tan | Cot | Sec | Csc | |
|---|---|---|---|---|---|---|---|
| 0° | 0.0000 | 1.0000 | 0.0000 | ∞ | 1.000 | ∞ | 90° |
| 1 | .0174 | .9998 | .0175 | 57.29 | 1.000 | 57.30 | 89 |
| 2 | .0349 | .9994 | .0349 | 28.64 | 1.001 | 28.65 | 88 |
| 3 | .0523 | .9986 | .0524 | 19.08 | 1.001 | 19.11 | 87 |
| 4 | .0698 | .9976 | .0699 | 14.30 | 1.002 | 14.34 | 86 |
| 5 | .0872 | .9962 | .0875 | 11.43 | 1.004 | 11.47 | 85 |
| 6 | .1045 | .9945 | .1051 | 9.514 | 1.006 | 9.567 | 84 |
| 7 | .1219 | .9925 | .1228 | 8.144 | 1.008 | 8.206 | 83 |
| 8 | .1392 | .9903 | .1405 | 7.115 | 1.010 | 7.185 | 82 |
| 9 | .1564 | .9877 | .1584 | 6.314 | 1.012 | 6.392 | 81 |
| 10 | .1736 | .9848 | .1763 | 5.671 | 1.015 | 5.759 | 80 |
| 11 | .1908 | .9816 | .1944 | 5.145 | 1.019 | 5.241 | 79 |
| 12 | .2079 | .9781 | .2126 | 4.705 | 1.022 | 4.810 | 78 |
| 13 | .2250 | .9744 | .2309 | 4.331 | 1.026 | 4.445 | 77 |
| 14 | .2419 | .9703 | .2493 | 4.011 | 1.031 | 4.134 | 76 |
| 15 | .2588 | .9659 | .2679 | 3.732 | 1.035 | 3.864 | 75 |
| 16 | .2756 | .9613 | .2867 | 3.487 | 1.040 | 3.628 | 74 |
| 17 | .2924 | .9563 | .3057 | 3.271 | 1.046 | 3.420 | 73 |
| 18 | .3090 | .9511 | .3249 | 3.078 | 1.051 | 3.236 | 72 |
| 19 | .3256 | .9455 | .3443 | 2.904 | 1.058 | 3.072 | 71 |
| 20 | .3420 | .9397 | .3640 | 2.747 | 1.064 | 2.924 | 70 |
| 21 | .3584 | .9336 | .3839 | 2.605 | 1.071 | 2.790 | 69 |
| 22 | .3746 | .9272 | .4040 | 2.475 | 1.079 | 2.669 | 68 |
| 23 | .3907 | .9205 | .4245 | 2.356 | 1.086 | 2.559 | 67 |
| 24 | .4067 | .9135 | .4452 | 2.246 | 1.095 | 2.459 | 66 |
| 25 | .4226 | .9063 | .4663 | 2.145 | 1.103 | 2.366 | 65 |
| 26 | .4384 | .8988 | .4877 | 2.050 | 1.113 | 2.281 | 64 |
| 27 | .4540 | .8910 | .5095 | 1.963 | 1.122 | 2.203 | 63 |
| 28 | .4695 | .8829 | .5317 | 1.881 | 1.133 | 2.130 | 62 |
| 29 | .4848 | .8746 | .5543 | 1.804 | 1.143 | 2.063 | 61 |
| 30 | .5000 | .8660 | .5774 | 1.732 | 1.155 | 2.000 | 60 |
| 31 | .5150 | .8572 | .6009 | 1.664 | 1.167 | 1.942 | 59 |
| 32 | .5299 | .8480 | .6249 | 1.600 | 1.179 | 1.887 | 58 |
| 33 | .5446 | .8387 | .6494 | 1.540 | 1.192 | 1.836 | 57 |
| 34 | .5592 | .8290 | .6745 | 1.483 | 1.206 | 1.788 | 56 |
| 35 | .5736 | .8192 | .7002 | 1.428 | 1.221 | 1.743 | 55 |
| 36 | .5878 | .8090 | .7265 | 1.376 | 1.236 | 1.701 | 54 |
| 37 | .6018 | .7986 | .7536 | 1.327 | 1.252 | 1.662 | 53 |
| 38 | .6157 | .7880 | .7813 | 1.280 | 1.269 | 1.624 | 52 |
| 39 | .6293 | .7771 | .8098 | 1.235 | 1.287 | 1.589 | 51 |
| 40 | .6428 | .7660 | .8391 | 1.192 | 1.305 | 1.556 | 50 |
| 41 | .6561 | .7547 | .8693 | 1.150 | 1.325 | 1.524 | 49 |
| 42 | .6691 | .7431 | .9004 | 1.111 | 1.346 | 1.494 | 48 |
| 43 | .6820 | .7314 | .9325 | 1.072 | 1.367 | 1.466 | 47 |
| 44 | .6947 | .7193 | .9657 | 1.036 | 1.390 | 1.440 | 46 |
| 45 | .7071 | .7071 | 1.0000 | 1.000 | 1.414 | 1.414 | 45 |
| | Cos | Sin | Cot | Tan | Csc | Sec | Angle |

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